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INVESTIGATION OF THE ENVIRONMENTAL IMPACT AND ENVIRONMENTAL DAMAGE FROM CITY TRAFFIC - NOISE AND EXHAUST GASES

PARTIAL STUDY II.3. DETERMINATION OF THE ECONOMIC COSTS OF THE STRESS FROM AUTOMOBILE EXHAUST GASES AND THE PROPORTION OF THEIR MARGINAL COST

ENVIRONMENTAL PROTECTION AGENCY,
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– NOISE AND EXHAUST GASES –

Partial Study II 3	Determination of the economic costs of the stress from automobile exhaust gases and the proportion of their marginal cost.
Assessor:	Prof. Dr. Rainer Willeke Director of the Institute for Commercial Science at the University, Cologne

Under contract from the Federal Minister of Commerce

Prof. Dr. Rainer Willeke
Director of the Institute for
Commercial Science at the
University, Cologne

5 Cologne, May, 1973
Universitätsstrasse 22
Telephone: 470/2264

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Partial Study II 3 Determination of the economic costs of the stress from automobile exhaust gases and the proportion of their marginal cost.

Authors:

THEORETICAL BASIS

Prof. Dr. Rainer Willeke

EMPIRICAL QUANTIFICATION

Dipl.-Economist. E. A. Marburger

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TABLE OF CONTENTS

		Page
List of tables		iii
List of figures		v
THEORETICAL BASIS		1
1.	Environmental problem and economic system	1
2.	Environmental stresses as external effects and social costs	2
3.	From the microeconomic to the macroeconomic solution	4
4.	Collection and evaluation	7
5.	Environmental stress and the cost concept	8
6.	Direct and indirect understanding of costs	10
7.	From trial of the cost-utility analysis to statement of cost-effectiveness analyses	13
8.	The method of goal-determined preventive costs	16
9.	Marginal costs of environmental stress	18
EMPIRICAL QUANTIFICATION		22
Introduction		22
I.	The evaluation of the excess over the 24-hour average	25
	A. Methodology	25
	B. On the results	34
	1. Application of the specified immission functions	34
	2. Application of the general immission functions	41
II.	On the economic evaluation of exceeding the half-hour averages	46
	A. Methodology	47
	1. Continuous cost curves	
	2. Discontinuous cost curves	56
	B. Empirical results of evaluation of excesses of the short-term average	58

Page

III. Conversion of the percentage emission reductions into absolute cost figures 65

A. On costs for individual vehicles 67

B. The costs for the entire vehicle population in the German Federal Republic 71

IV. The effect of reductions in peak traffic in the inner city region on the environmental situation 81

A. Noise 83

B. Exhaust gas emissions 84

1. Effect on exceeding the short term value 85

2. Effect on exceeding the long term values 86

3. Financing effect 87

V. Damages to materials from automobile exhaust gases (buildings, art objects) 91

Summary 93

Appendix 100

Selected Bibliography 117

LIST OF TABLES

		Page
1.	Relative emission reduction ratios in % for CO for the individual measuring days (long term values), determined using the specified immission functions (measuring point 5)	37
2.	Relative emission reduction ratios for CO for the individual measuring days (long term values) determined using the general immission functions (measuring point 5)	43
2a.	Relative emission reduction ratios for CO for the individual measuring days (long term values) determined using the general immission functions (measuring points 1, 2, 4 and 6)	44
3.	Comparison of the averages of the reduction ratios determined using the specific functions with the results from the general functions	45
4.	Degrees of reduction for the Technical Monitoring Union questionnaire to the automobile industry	57
5.	Relative reduction quotas in % for CO for excesses over the short term values, determined using the specific functions (measuring point 5).	60
6.	Emission reduction quotas in % for CO for the excesses over the short term values, determined with the general immission functions (measuring point 5)	61
6a.	Emission reduction quotas in % for CO for the excesses over the short term values, determined with the general immission functions (measuring points 1, 2, 4 and 6).	62
7.	Comparison of the averages of the reduction quotas determined with the specific functions with the results from the general functions	64
8.	Summary of literature statements about the increased costs related with exhaust gas-reducing measures.	100
9.	Increased expenses per vehicle for measures to reduce exhaust gases, depending on the degree of reduction.	69
10.	Effect of technical progress for the development of costs for exhaust gas-reducing measures on the vehicle	70

Page

11. Increased cost per vehicle as a function of the degree of reduction, considering technical progress, in DM. 72

11a. Allotment of the total costs per vehicle to the city kilometers driven. 73

12. Sum of the increased costs for exhaust gas-reducing measures for all newly licensed cars in the German Federal Republic from 1973 to 1982, depending on the degree of reduction 80

13. CO emission as a function of the degree of congestion 84

14. Effect of a traffic peak reduction on the long-term value. 87

15. Annual driving of vehicles in cities, according to city size classes. 88

16. Annual driving of vehicles during traffic peak periods in cities, according to city size classes 88

17. Annual driving of vehicles at reduced traffic peaks in cities, according to city size classes 89

18. Financial effect of a price-policy charging system for traffic peaks, depending on the price elasticity of the demand, in billions of DM per year. 90

List of Figures

		Page
1.	Immission function for the model block L_x.	29
2.	Driving mode as a function of traffic volume for some Cologne measuring site.	33
3.	Immission function and dependence of the reduction ratio on the traffic volume.	49
4.	Avoidance costs as a function of the excess over the immission limit.	50
4a.	Increased costs as a function of the degree of reduction (Heitland).	53
4b.	Increased production costs as a function of the degree of reduction (Dornier).	53
5.	Avoidance costs as a function of the traffic volume.	54
6.	Identical avoidance costs with different excesses above the immission limit.	55
7.	Stepwise course of the cost curves	59
7a.	Production limit - production mean - type test limit - modal value.	66
8.	Time lag between the equipping of new vehicles with exhaust gas-reducing measures and the effect on the total emission.	79

THEORETICAL BASIS

1. ENVIRONMENTAL PROBLEM AND ECONOMIC SYSTEM

The economic aspects and weight of the stress situation currently discussed as the environmental problem were first detected and analyzed by economic science in the market economy system of the practical world. This corresponded to its leading position in industrial development. The nature of the scientific procedure, the concepts applied, as well as the starting point and the execution of recommended solutions even today reflect this traditional relation, even with the current state of environmental economics. This obviously does not by any means indicate that the actual situation of ecologically damaging or stressing emissions, or the depletion of natural resources, can be explained as due to this economic order, or exist only in it. Such arguments are easily refuted, because the real phenomena and importance of environmental stress and depletion are due solely to the actual conditions and courses of certain production, consumption, and commercial processes. They occur as the result of technical causes at the comparable status of economic development in all economic systems. They are a challenge for every system, and have many similar problems accessible to an exchange of experience. To be sure, with this fact we must link the opinion that knowledge of the specific economic sides of the problem and the economic-political conclusions derived from them, i. e., the classification of the problem in its economic relation and the development of concrete strategies for environmental protection must proceed out of the existing economic and social order and must be related to them.

2. ENVIRONMENTAL STRESSES AS EXTERNAL EFFECTS AND SOCIAL COSTS

External effects and relations in the processes of production and consumption between economic subjects, which have a positive or negative influence on their economic position as producers or consumers, without entering into the evaluation and coordination process of the market; i. e., into the price-cost calculations which control decisions.

Social costs, then, indicate the external effects which are negative in nature. These are the parts of the costs which arise from certain production or consumption decisions but which are not borne by the decider (causer), but by other economic units or even a social whole.

Economic science gained access to the environmental problem as early as the beginning of the twentieth century, with the interpretation of emission-immission relations causing external stresses as social costs. At the same time it gained a primary view of the evaluation and solution of these problems.
If certain cost components remain unconsidered in the cost calculations of the originator, this means that the private costs relevant to the decision do not make up all the actually occurring costs. This leads to distortions in competition and as a result to lack of control in use of production factors. Simultaneously, it leads to departures from income distribution according to efficiency. Neither the production optimum nor the distribution optimum of a fully functional competitive system can be attained. If, on one hand, it happens that the production and availability of particular goods is overextended according to the scale of a complete economic computation, because the weight of the costs is underestimated in this case, then on the other hand, production remains too low for those goods having private costs occurring with other productions, which would have had to enter into the cost calculation.

The first proposed solution follows this program sketch. The diverted part of the cost, which would be applied externally, must be determined, weighted, and transferred by suitable measures of economic, financial and political nature to the decision-controlling private calculations of the originator. Through such internalization of previously external costs we produce a complete cost calculation and application of them corresponding to their origination. The private costs and the social costs of individual products are then identical. The suggested instrument for such internalization is control of the level of the external costs applied to the originator, even with respect to monetary compensation, particularly as a stimulus for avoiding or reducing the actual situation to be controlled in the direction of reducing externally stressing emissions.

This concept, essentially developed by A. C. Pigou, was a pioneering effort. But even in respect to the comparatively minor stress situations existing in the first decades of this century it had great weaknesses. In particular, the argument acknowledges an unattained and probably never attainable amount of information. As is well known, not only the technological-natural scientific effect relations and classification had to be identified and measured, but even the economic valuation of the stressing situation in respect to consequences for humans, in money units. Only in this way can we understand the application of the cost concept and the requirement for internalization of the social costs through originator control.

3. FROM THE MICROECONOMIC TO THE MACROECONOMIC SOLUTION

The occurrence of external effects and of social costs in particular, of extent which is noteworthy and therefore economically and socially-politically relevant,can be considered as an exceptional phenomenon throughout, which should be identified and treated from case to case. This considered primarily individual production examples which emitted particularly strongly (e. g., cement industry) and a limited and relatively easily recognized group of persons stressed. As for the damages caused, the cost-increasing or return-reducing damage from other products appeared to be the primarily significant case, e. g., a reduction of economic yield which could be quantified through before-after comparisons. The catch-words of "social costs" were also used to speak of an only occasionally detectable inadequacy of market economical self-control. Opinions of its actual importance diverged widely. The problem indicated a lack of elegance in the market system, not in any case to a question of existence of the economic and social order.

The penetrating change to objective problem weights which occurred in the meantime, and the simultaneous change in formation of public opinion, arose and still arises primarily from the accelerated progress of industrialization, with particularly strong growth in activities with particularly strong emissions, and from the movement to cities and concentration in population which ran parallel with that. These developments lead not only to a strong growth of the stressing emission-immission condition in all, or of greater areas and time spans, on the average, but in particular also to spatial and temporal concentrations of the stress. These resulted in actual minor, but reliably visible, dangers for the human living position and for the prospects of future development of life for the individual person and for society.

Here quantity is converted into quality. This corresponds also to a new consideration of the problem in economics. In place of the particular individual economic meaning with discussion of microeconomic countercontrol, there appeared a total economic problem analysis which could support comprehensive strategies of avoidance, reduction, and control of damage.

But the new macroeconomic access to the economic or economically significant area of problems and objectives in environmental stress proceeds not only from the high weights and increasing necessity attained in the meantime, but also from the very wide, almost universal spread of the situation under discussion. The relations which were pursued first for special cases, and the insignts obtained from them, are now being transferred and generalized to the system relations in the whole economy. The environmental stresses in the form of emissions which are injurious or which reduce well-being are to be considered as negative-valued accompanying phenomena following from the technologies used – quasi by-products – of extremely many economic activities. These, to be sure, belong primarily to the production sphere, but in part they originate in connection with consumption and government activities. With an interpretation of the processes discussed according to production theory and exchange economics, the situation requiring correction can be presented so that the producer of the negative outputs receives no compensatory amounts or, if an alternative formulation more applicable in many cases is chosen, so that claims on scarce resources, and resources progressively becoming scarcer, meet no rationally limiting and selecting barriers of scarcity prices.

In order to be able to eliminate the distortions in economic calculations and the errors which they induce in the economic flow of value, first by model simulation but later in reality, if possible, several methods have been developed and discussed. In the part of environmental economics concerned with basic research, two methods have attracted the most interest. These are the methods of the phantom price and that of the expanded input-output analysis. By the former route, the entire economic price structure should be corrected by additional amounts for the previous "cost-free inputs" and for "negative outputs" in the direction of a price-cost calculation completely including the consumption of value. The second route is aimed at supplementing the conventional input-output model of intersectoral entanglement through treating environmental stresses as outputs and the claims on the environment as inputs, resulting in a supplemented and clarified total picture of the economic-ecologic relationships. These two methods can be combined with each other. Then they give a very useful and analytical guiding picture. They serve to introduce the economic problem content and at the same time give a view of which information must be available to make the problem and objective area clear. The heuristic value is great, and is based similarly to that of Pigou's pioneering work. But they have corresponding weaknesses, which actually extend to the impossibility of completing the model. The calculation systems are based on knowledge of both the amounts of physical stress and their interlacing in the economic system, as well as the economic weighted values for these amounts, so that the different physical measurements can be converted into a uniform economic measuring system for a monetary calculation. In fact, the information assumed to be existing or attainable on the ecological effect relations and on the ecological-economic dependences are not available, and can not even be obtained with the current status of ability of the collection and evaluation methods.

4. COLLECTION AND EVALUATION

Between the theoretical economic model designs which aim at a comprehensive and systematic inclusion of the social costs due to environmental stresses into the economic calculation structure, and the actually existing possibilities for unambiguously understanding the actual state of the stresses and expressing them in monetary terms as costs, there is a gap which is at present unbridgable. Also characteristic for this is the fact that the research work in the field of environmental economics is being done on two separate fronts. The models directed toward general orientation and to integration of the "environmental stress" complex into economic theory treat this complex as a single problem and so are subject to experimental transparency with respect to the social costs to be internalized. The concrete phenomena of the actual stress situations, which differ greatly individually, and also the practical problems of certain avoidance, reduction, and compensation strategies are always discussed by examples. Thus, the fact that there is no generally accepted listing of situations which apply or should apply to environmental stress and which are bounded off from other problems and problem fields for correcting or supplementing economic and commercial policy can remain of no interest. Along with the generalizing direction of research, of course, there also runs a multitude of intensive efforts to analyze the economic aspects and consequences of specific individual concrete types of stress and to understand the degree of stress existing or predicted in the particular field of manifestation. Here we can mention in particular the stresses from noise and exhaust gases, with further potential for splitting up according to the various emission sources (e. g., street traffic) and by the major regions stressed (e. g., congested city areas).

Basically, the division of labor and cooperation between the two directions of research must proceed so that through practical areas of research we can obtain that partial data which is suitable and necessary for incorportaion into the total model. The hope for an uninterrupted regular supply with data suitable for the model remains unrealistic for the present because the partial data on costs and stress and on costs of measures to reduce the stress, obtained in the various concrete stress areas, cannot at present be comparable, so that they cannot be integrated directly. Actually, the problems and difficulties for specific areas are of such different forms that it does not yet appear possible to conceive a uniform methodology for cost calculation. This experience has led to different methods being developed for direct and indirect cost determination for analysis of certain individual stress areas, and combining data according to the status of obtainable data.

5. ENVIRONMENTAL STRESS AND THE COST CONCEPT

The collective designation "environmental stress" includes many very different phenomena. Common to them is a negative, harmful or injurious effect for the life and activity of humans, as well as the fact that the relation of cause and effect extends beyond the purely private and, therefore, internal relations of individuals or small groups (e. g., families). The negatively acting relation is also produced on "other" people or on power groups of "other" people or even on installations and property of public bodies. For the development of such a relation to the "environment" it is not necessary, however, that the originator and the stressed (harmed) belong to different groups and face each other as groups. Often both sides are in the same group, and the affected persons are among the originators. This is particularly true for highly fragmented emissions distributed over many sources, as for production of noise and exhaust gas by automobile traffic. It might even be questionable whether the fact that aside from those involved as originators, there are still other persons or groups of persons who are affected, significant as it is in respect to questions of stress and avoidance strategies, is of particular importance for characterization of the actual situation. Because even in the limiting case when the originator and the stressed clearly make up one and the same group and the individual emissions and immissions correspond to each other, there would be an environmental relation if their own role is not clear to the participants in the relations, and can not be clear, so that special methods for collection and evaluation must be applied to clear them up, far exceeding the potentials and responsibilities of individuals.

As for emissions of vehicles in particular, we must think of the participants as not only the drivers themselves but also the circle of more or less regular riders. One might go even further and speak of the society as a whole. The fact that there are vehicles and traffic has become a condition of its life style and standard of living which we can hardly think of doing away with. Thus, society participates at least indirectly in the positive potential, so that it seems unjust to view only the negative aspects on the side of those affected. Of course, such a suggestion may not ignore the fact that in many cases the distance between the extent of the stress and the amount of any possibly indirect participation is unusually great.

Emission-immission relations prove to be an environmental stress because of their negative effect. Elimination of the immission or a reduction of the degree of immission would, correspondingly, improve the situation. This improvement can affect the consumer field and then represent a rise in the support level of people; but it can also relate to production processes and thus appear as an increase in the productivity of the use of production factors. In any case it is obvious that the actual situation of immission loading, which at least is a bad effect and perhaps leads to injuries, should be brought into relation with the concept of costs and that one should attempt to express the weight of load situations and their development in cost figures.

6. DIRECT AND INDIRECT UNDERSTANDING OF COSTS

There are, to be sure, various starting points and procedures for using the cost concept. One first attempt, exactly matching the question proposed, is directed at determining the stress situation caused by immission, according to the degree of the stress, directly as a monetarily quantified negative value (damage). This procedure is ordinarily possible, at least approximately, if the nature and direction of the stress refers to production processes and calculable yield reductions or material losses in earning power (e. g., reduced harvests, reduced fish or game crops). Also, reductions in the value of plots of ground, particularly those with specialized uses (hotels, sanitaria, etc.) are basically determinable by means of the market price variation. But very considerable difficulties appear in practice due to the fact that the tendencies for change in value due to immissions in the case of real estate are often overlaid by other price changes, as from special shortage situations, or even through political intervention.

On the other hand, damages which affect the level of satisfaction, the health, and the lifetime of humans can only in exceptional cases be included in the direct route for collection and evaluation. The problem this raises could be answered positively only if, in a certain extent, shortened life expectancy or a reduced earning time (sick periods, early incapacity) could be ascribed to the immission stress and if there were an economic scale available to evaluate the loss in lifetime or earning time (the latter can be considered approximately to exist). But we do not have enough knowledge for this. With respect to range, the route of an auxiliary calculation would be more passable. That is, if there had been occasional sicknesses or even long-lasting losses to health as a result of immission stress, requiring demands on medical services, medical and other treatment, hospital stays, cures, etc., then with the costs of these investigatory and curative measures we would have available an important scale for evaluation. But even for that we have at present only partial information, which is in no way sufficient for a systematic calculation. Furthermore, the causal assignment is difficult in the medical-diagnostic opinion and essentially insoluble in many cases because of sets of symptoms having multiple causes. Finally, we must not overlook the fact that the treatment costs generally, especially for competent medical services, depend, in order of magnitude, on the severity of the existing or developing damage situation. But in spite of the weight of the actual or potential damage they cannot be reproduced because we are dealing with successive related but not identical situations.

The situation is quite similar for application of the same basic idea to damages to private or public property, leading to repair, restoration, and protection measures, among others. Here, as a rule, we are subject to proportionality between the extent of the damage and the repair cost actually expended, or held to be "necessary". But, of course, the damages to objects (reductions in value) and the current or planned repair costs are not identical. Here, in fact, there can even be special problems in relation to judgement, subjective evaluation, and ability to pay. These can lead to departures from proportionality between the extent of damage and the repair costs.

In many cases, therefore, the direct collection and weighting by cost of environmental damage situations and damage developments has gaps. In other cases, it is not possible at all with the present state of knowledge. The latter is clearly true for the effect of vehicle immissions on people, with respect to reduction of well-being, damage to health, and reduction of life expectancy. For this region of stress, the direct determination founders even in the preliminary, still completely hopeless attempt to establish, through medical-diagnostic research results, a sufficiently comprehensive assembly of distinctly assignable actual damage situations.

Therefore, we must test the route of indirect cost estimation for its predictive potentials. This type of procedure is linked with measures which are suitable for eliminating the stressing immissions or, as is the rule, reducing them (prohibitive measures). Most of these measures are aimed at reducing the immission values through technical changes (active prohibitive measures). Other alternative or supplementary measures reduce the load values on the route from emission to immission (passive prohibitive measures, such as screening measures for noise protection). Changes and modernizations of one type or another require costs, or added costs, in comparison with the previously existing situation. These costs can be determined or estimated for technically clarified projects by considering the existing or expected production and marketing details. These costs or added costs oppose the stress reductions effected. Depending on the starting point for the measures, these appear first as reduction in the emission values, which leads to an immission value reduction, or, for passive measures, only as an immission value reduction. In both cases, if sufficient informative measurement results are available, it is possible to assign the costs for certain prohibitive measures, stated in cost units, to reductions in the stress situation, expressed in technical mass units. The cost of the measures depends on the nature and extent of the plans and, for a stepwise program, also on the planned time steps for the realization of the objectives. But they are obviously not identical with the cost value of the damage quantities which disappear due to the measures. This statement is obvious, and valid in spite of the fact that the damage situations and changes of the damage situations currently avoid direct quantification. The regular experience that at a given state of technical knowledge, certain added preventive costs, after an efficiency threshold is passed, give steadily decreasing reductions in the load, is a sufficient indication of that. If a large number of objective situations with downward-stepped load values are to be tested, realization of each subsequent best situation, after the threshold is passed, requires progressively increasing costs. For this reason, we can produce an informative relation which from certain preventive costs leads to a monetary weighting of load situations or of changes in the load situation only on the basis of a prescribed goal or a prescribed evaluation of several degrees of attainment of the goal.

7. FROM TRIAL OF THE COST-UTILITY ANALYSIS TO STATEMENT OF COST-EFFECTIVENESS ANALYSES

As was established, direct determination and weighting of the costs of environmental stresses currently seems unfeasible in many cases, for example, with respect to the negative effects of noise and exhaust gas due to vehicles in city traffic. In part, it appears impossible over the long term. Yet it is useful, in a thought experiment, to proceed from the unrealistic assumption that we are given the prerequisites for a direct measurement of damage in cost values. This deliberation allows recognition of the ideal concept of an economical-analytically based environmental protection policy.

The following data is considered given:

a) As the emission function, the quantities of emission generated from a variable volume of sources (e. g., through an amount of vehicle traffic per unit time, with a certain composition, in an adequately described set of parameters); and, derived from that, the immission function relevant for characterization of the damage situation.

b) The cost function expressed through recalculation of the immission function into monetary quantities.

c) The preventive measures possible for the state of technical knowledge, with effectiveness and cost data, arranged in the sequence of increasing costs and stress reductions.

Now if both the reduction measures with their costs and the positive effects measured as a reduction of social costs (diminished or avoided costs equal to the established utility) have steady courses, then any additional amount of preventive outputs can be compared with the resulting decrease in damage, expressed in decreasing costs. As long as the increased costs of prevention are below the reduction in social costs produced (equal to the established utility), we have demonstrated the economic improvement of a situation.

The measure is presented as "economically profitable" according to the social utility - cost ratio. But the latitude for improvements in the situation is completely exhausted if the possible preventive measures are applied in the sequence of decreasing economic profitability up to that measure or partial measure (step of a measure) at which the added costs required produce only an equally great decrease of costs in the stress area.

This calculation concept, and, with it, the establishment of an optimal ratio between preventive expenditures and preventive effects corresponds to the procedure of cost-utility analysis. But, to repeat once more, the application of this method to the real problem being discussed is impossible with the status of information actually attainable. The stress situation and changes in this stress situation, presented on technical scales, cannot be transformed directly into cost figures.

On the other hand, there are technically suitable designs and methods, known in a considerable and rapidly increasing extent, by which the values of the noise and exhaust gas emissions from vehicles can be reduced. Also, the costs of such emission-reducing measures and groups of measures are to a large part reliably estimable. Basically, they can always be determined to a good enough approximation. Further, with respect to knowledge of the spread of emissions and, with that, the buildup and degradation of immission situations, there are no particular difficulties for the case of traffic noise. To be sure, the same point represents a number of difficult and not yet finally solved problems for the exhaust gas side, with the effects of changing weather factors making the situation particularly difficult.

Nevertheless, we can consider it possible to relate the immission values of the stressed situations to certain amounts of emissions reliably enough that we can also state, in the opposite direction, the extent to which the emissions must be reduced if the level of stress (immission value) is to be lowered to a certain planned or considered extent so that a certain target level shall be reached if necessary.

With a given stress situation and a given state of relevant technical knowledge, the extent of the necessary preventive measures depends on the goal level desired and, thus, on the initial difference between the actual and desired levels, as well as on the time period within which the desired level is to be achieved. Aside from exceptional cases in which utilization of the technical possibilities is not a problem with respect to the periods of application and adaptation, or, conversely, in which the technical changes require a completely determined, unchangeable time, the period of time in which a certain goal level or a certain series of stepwise intensified goal levels is to be obtained is highly important for the form of the cost.

8. THE METHOD OF GOAL-DETERMINED PREVENTIVE COSTS

Final decisions on which goals are to be realized in what periods must be based on political decisions, through a process of political opinion and desire development. Many more or less reliable data enter into this process, both on the extent and consequences of the existing and developing stress situation, and on the economic and other consequences of reduction and elimination strategies. This deals with preliminary and incomplete information, and often with information clearly requiring correction. There are large gaps in information, such as for the medically significant long-term effects of noise and exhaust gas emissions from vehicular traffic at the loading strengths which have been reached or which are predicted for the future. It follows that in judging measured with definite objectives, requiring preventive expenses in a certain extent, there can be, and generally will be, a difference in opinion about weighting of cost-utility relations. But with the breadth of interests and value judgements, it is hardly to be feared that a position which cannot yet be made compatible with the state of reliable knowledge will be without recommendations and contributions to argument.

Thus, if the material and temporal goal is fixed as the result of a political decision process, scientific research makes it easier to find this decision through application of supplementary and improved information, narrowing the range of more or less arbitrary judgement.

Certain economic loads (costs) are linked with the establishment of any objective. The politicially required level demanded, or even a stepwise program with increasing requirements can, therefore, not be established without consideration of the resulting load. This can also be expressed by saying that in the process of political opinion development, the readiness of the society to pay for certain improvements in the situation must be established (social readiness to pay). This readiness by no means depends only on the degree of consciousness of the stress problem under consideration, but also on the state of development and the average per capita income of the economy, and on the number, type, and allotted urgency of the alternative uses of private and public money, which would be absorbed by certain environmental protection orders.

With the fixing of the goal and the decided social readiness to pay, there is an indirect economic evaluation of the existing or predicted stress situations, because the value of the desired improvement (social cost decrease in the stress area) must be set equal to the expense accepted for it (the preventive costs as the goal-dependent increased costs). This includes the judgement that with continuing preventive costs the value of the additional improvement in the situation is less than the value of the additional expenses with their alternative potential uses. Thus, the decision establishes an amount, and it then serves as a criterion for rational bargaining, if the decision process is supported by the best possible utilization of all available information.

9. MARGINAL COSTS OF ENVIRONMENTAL STRESS

If we are given a definite set of conditions including the relevant parameters, then the immission value indicating the degree of loading from noise and exhaust gas due to vehicles depends, among other things, on the emission volume of a certain amount of traffic (vehicle flow). If the amount of traffic changes with otherwise identical conditions, this causes a similar change of the emission volume and, corresponding to a regularity in diffusion, also of the immission value. Other things being equal, the amount of traffic and the degree of loading are positively correlated. Now if one considers the amount of traffic as the independent variable, any increase in the vehicular traffic by small steps can be assigned to an increase in the load situation (increasing immission value). The introduction of such a functional dependence suggests the concept of the marginal costs.

By marginal costs, we mean the increase in costs caused by expanding production by one more production unit. For practical reasons, we can replace the expression "unit of amount" describing the variation introduced by "small partial quantity", and the differential ratio by the ratio of differences. Marginal costs are then the costs per unit amount of production which arise additionally from a (relatively small) increase in the amount of production. The derivation of the marginal cost is generally referred to a given production capacity (short-term marginal costs). With increasing utilization of capacity (business), then, they will at first decrease or even remain constant; but as the limiting capacity is approached, they increase strongly and finally steeply. The reference to amounts of definite products indicates that the units or partial amounts considered are homogeneous among themselves. This is an essential prerequisite for precision of the marginal cost concept.

The marginal cost concept, developed for purposes of cost accounting and pricing policy in the field of industrial production,can only with modifications be utilized for the economic analysis of the noise and exhaust gas stress caused by vehicle traffic. As the "production amount", we must understand the amoumt of traffic of a definite composition. If the amount of traffic is varied by partial amounts, the amounts added or removed must have the same composition as the original total amount (homogeneity requirement). In this conceptually established set of conditions, increasing numbers of vehicles cause increasing values for the noise and exhaust gas stress. According to the concept of marginal cost, we must first determine that increase in loading caused by relatively small increases in the traffic flow, then indicating a "quantity unit", something of a representative vehicle with the mean properties of the total quantity which are relevant to this question. This solution satisfies the requirement for practicability, which must be excluded for the alternative formulation "increase in load caused by insertion of another vehicle into a given traffic flow".

According to the specified procedure, the marginal noise and exhaust gas loading must be determined as a function of the traffic volume with the technical scale of immission values. As a direct conversion of the technical load values into the monetary values of an economic cost calculation is not possible, the social marginal costs for environmental stress must be determined indirectly by using the concept of the goal-determined preventive expense.

Let there be given an immission function as a function of the amount of traffic, the actual stress situation (perhaps differentiated by situations) and the desired loading (limiting value or many situation-related limiting values) for each set of conditions (city model block) considered. Now the problem is that of realizing the desired situation from the actual one, and estimating the cost consequences of this requirement.

The simplest case, which would also allow an unforced application of the marginal cost consideration, would exist if, with rise in the amount of traffic according to the trend, the actual loading just agrees with the established limiting value, or if the increasing actual loading approaches this limit. Then those stress-reducing measures would be provided which are suitable, with minimum preventive costs, of stopping completely the expected increase in stress, so that the required limit is maintained. By limiting costs for noise or exhaust gas load, we mean the amounts of additional preventive measures which must be employed to maintain prescribed desired immission values (limiting values) if the amount of traffic rises, by relatively small partial amounts in the time span of a time series.

If, on the other hand, the actual load value in the initial situation is significantly above the required limiting value, then an appropriate reduction in the load level must first be planned, and the costs (preventive costs) of such a measure (group of measures) must be accounted for before the marginal load - marginal cost concept can be applied. If the level reduction presupposes a program with steps in time, or if it is in any case so applied, then, to be sure, both trial solutions can and, strictly taken, must, be combined. For the necessary reduction in level, which in reference to the point in time is applied to a certain amount of traffic, there are other preventive costs, which are suitable for compensating the effects of the further increase in the amount of traffic.

EMPIRICAL QUANTIFICATION

INTRODUCTION

The previous considerations have made it clear that an economic evaluation of the noise and exhaust gas loadings due to inner-city traffic is not yet possible by the direct route (determination of the actual damages assignable to these loadings). This would be possible only if particular damages to health could be quantitatively-functionally assigned unambibuously to the immissions. The consequence of this information gap for the economists is determination and evaluation of the goal-determined expenses which are necessary to avoid such damages or to maintain politically or medically specified immission limits.

With respect to exhaust gases, therefore, the question of the relation between the emitting activity and its importance or effect on the immission side became the central problem. Thus, it revolves around the problem of the quantity by which the emission must be changed (reduced) in order that the immission limit be attained, or not exceeded. Here, too, there are almost insuperable difficulties at present. Operational functions about the direct relation between vehicle emission and immission do not now exist. It is possible to use, for a model, laws transferred from the spreading relations for stationary sources to the moving emission source, traffic. (1)

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(1) See Dreyhaupt, J. J., Air Quality Maintenance as a Factor in City and Regional Planning [Environmental Protection Publication Series, Rhineland Technical Monitoring Union (Editors), Volume 1], Cologne 1971, p. 98 ff.

The route presented here is, then, best seen as a first pragmatic attempt to approximate a possible solution. After much effort, the working group of the Rhineland Technical Monitoring Union (Partial Study II 1.1) has been able to use regression calculations to define, for some city model blocks (see Report of Dr. Glück, Partial Study I 1.1), functions which state the dependence of the half-hour averages of the CO immissions (1) on the traffic volume. These are functions of the type: $I_{CO} = e^{a} + e^{bn'}$, where n' indicates the current traffic volume. Such functions were found first for four model blocks (1, 2, 4, and 6) by Dr. Glück's working group. These are also differentiated for each model according to different meteorological parameters (3 wind direction classes and 3 wind speed classes). They represent a choice of particularly critical individual situations. In all, 20 such immission functions are available. In order to increase their general validity, the Rhineland Technical Monitoring Union developed five more functions for the model blocks 1, 2, 4, 6 and 10. These functions do not differ according to meteorological factors, but apply to the particular model type for all climatic conditions. All the immission functions used here were obtained from data for measuring point 5 (0.75 m high, at the edge of the sidewalk). The general (not the specific) functions for the other measuring points (1, 2, 4, 6) must, however, be determined by using Table 9 on page 47 of the Technical Monitoring Union report. The reduction ratios which appear have been also determined for both long-term and short-term increases above the values. (See Tables 2a and 6a).

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(1) The treatment of the other pollutants, CH and NO_x, is still subject to technical problems of measurement. But this does not change the basic evaluation of the methodology proposed here.

The meteorological data deal with the current major wind situation at the Cologne-Bonn airport. For the details of the functions, particularly with respect to their claim for generality and their range of validity, as well as their derivation, see the research report of the working group of the Rhineland Technical Monitoring Union.

Unfortunately, these immission functions represent only the relation between the half-hour averages of the CO immission and the traffic volume. Functions for the 24-hour average are not yet available. This is particularly unfortunate because the half-hour limit (= 30 ppm) was exceeded only rarely in the Cologne measurements (in 38 of 4,050 cases). By contrast, the 24-hour average was above the medically specified limit (8 ppm) (1) on 14 of 27 measurement days for measuring point 5, on 8 of 27 days for point 1 (0.75 m high, building line), on 8 of 27 days for point 2 (1.50 m high, building line), on 7 of 27 days for point 4 (4.50 m high, building line), and on 12 of 27 days for point 6 (1.50 m high, sidewalk edge). Because great importance is placed on long-term values from the medical standpoint, we must also attempt to include these long-term value excesses economically in the concept. The short-term excesses are treated later.

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(1) The MIC_D value for CO is reported as 10 mg/m^3 (≙ 9 ppm) in Partial Study II.2. At the time the final report was written (beginning of 1973) this limit was apparently not yet defined exactly to a tenth of a ppm, as the rounding of the exact value, 8.54 ppm, to 9 ppm showed (for an air temperature of 20°C). In a discussion of the participating research groups at the time, it was considered entirely reasonable to apply a conversion ratio of 1 ppm ≙ 1.25 mg/m^3 (this relation applies for 0°C), particularly because of the background of immission measurements in metropolitan Cologne at temperatures partly below 0°C. This factor leads to the limit of 8 ppm used here.

The difference of 0.54 ppm does not affect the study, as the emission reduction stages for individual vehicles, for technical reasons, show a range of about 5% up and down. Furthermore, we must consider a potential measurement error of 5%, so that the value of 8 ppm is on the safer side.

I. THE EVALUATION OF THE EXCESS IN THE 24-HOUR AVERAGE

A. Methodology

For this investigation, the 24-hour average is defined as the arithmetic mean of 24 hourly or 48 half-hourly values (1). This simple additive combination makes possible easy determination of the necessary immission reduction for the concrete case. For instance, if the 24-hour average is 10 ppm, then each short-term average entering into the determination of this long-term value must be reduced by 20% in order to reach the 24-hour value of 8 ppm. This means nothing more than that a function of the half-hour average must be reduced by this relative amount in its entire range of validity. Such a function, e. g.:

$$I_{CO} = e^{a} \cdot e^{bn'} \cdot 0{,}8$$

would then describe the course of that immission function which after reduction of the original function by 20%, would lead to a 24-hour average of 8 ppm. Thus, we produce a connection between the existing half-hour average immission function and the 24-hour average.

The economic question, now, is what expenditure on the emission side is necessary to attain the desired reduction of the 24-hour average. This question would be easy to answer if there were a generally valid statement of the relation between emission and immission.

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(1) This definition can be only conditionally correct as an unambiguous effect-criteria-oriented limit determination. For the economic working group, however, it must be considered as a basic "input" prescribed by the medical working groups.

Here, one can make use of the direct proportionality of traffic volume and total CO emission. Then the total emission, E_{CO} on a line source, is determined as follows:

$$E_{CO} = \frac{\text{traffic volume} \times \text{length of the source}}{\text{average speed}} \cdot e_{CO} \quad (1)$$

where e_{CO} is the so-called specific emission factor which states the CO emissions of an average vehicle per unit time in a definite mode, such as has been obtained from extensive emission measurements by the Rhineland Technical Monitoring Union working group, made on a roller test stand using a representative cross section of the passenger cars used in the German Federal Republic.

The formula can be transformed into the following simple form:

$$E_{CO} = \text{vehicles/unit time} \cdot e_{CO} \text{ (in kg/vehicle} \cdot \text{km)} \quad (2)$$ (1)

It is immediately clear that with this relation it makes more difference whether the number of vehicles or the specific emission is reduced by a relative amount. The result is the same in both cases. In other words: The effect on the total emission which would be produced by a 50% reduction in traffic volume, for instance, is the same as if the emission of each individual vehicle were reduced by 50% with the same traffic volume. (2)

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(1) In this respect, see also Partial Study II 1.1, Tables 1 and 2 on pages 8 and 9.

(2) Admittedly, we presume here that the driving mode, characterized by the average speed, remains constant, because the specific emission factor, e_{CO}, also changes when the driving mode changes.

For this reduction on individual vehicles, there are certain ideas of the cost. Even though they vary within a wide range, they make an economic evaluation appear possible.

For evaluation of the excesses over the 24-hour average, this proportionality was used as follows:

In the first step, the immission function of half-hour averages which meets the requirement for a 24-hour average = 8 ppm was determined.

Then in a second step, we can compare the corresponding immission value, I_{CO}, reduced by a certain amount, which can be determined from the reduced immission function, with the traffic volume determined empirically for a concrete measuring day and a definite measuring site. With the basic function generally valid, this means that the immission value, I_{CO}' can be read for each definite traffic volume at a certain measuring site.

Finally, in a third step, we determine the traffic volume, n', at which the target value, I_{CO}' is realized in the original immission function. This is done mathematically as follows: The original function: $I_{CO} = e^a \cdot e^{bn'}$

is solved for n':

$$n' = \frac{\ln I_{CO} - a}{b}$$

One inserts I_{CO}' for I_{CO}, with the parameters of the original function fo a and b, obtaining the vehicle volume, n', for which the function has the value I_{CO}'. The relative difference in these two traffic volumes, or the reduction ratio, can also be interpreted, on the basis of the above-mentioned proportionality relation, as the percentage emission reduction which each individual vehicle must experience in order for the target value, I_{CO}', to be likewise realized with the traffic volume unchanged and the same driving mode (1).

A concrete example should make the procedure clear:

The 24-hour limit of 8 ppm is exceeded by 3.7 ppm = 32% at measuring site 3 on 4 November 1971. Because of the actual building situation, the Rhineland Technical Monitoring Union assigned this measuring site to model block 4.

For model block 4, there are three meteorologically specified and one generally valid immission function(s) for the CO half-hour average. Let us choose arbitrarily those for the wind direction 'downwind' and the wind speed of 0 - 3 m/s with the equation:

$$I_{CO} = e^{1,2} \cdot e^{0,0011\, n'} \qquad (1)$$

In the period from 9 to 9:30, a traffic volume of 1,600 vehicles/hour was counted. If the function is valid, we can use it to determine what value I_{CO}' would have at this site with a function reduced by 32%.

$$I_{CO}' = e^{1,2} \cdot e^{0,0011 \cdot 1600} \cdot 0,68 = 13,05 \text{ ppm} \qquad (2)$$

Now in order to find the traffic volume at which the empirically determined immission function has the value of 13.05 ppm, Equation (1) is solved for n', with I_{CO}' inserted for I_{CO}.

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(1) The same driving mode is an important premise for the proportionality hypothesis, which occurs in reality only with limitations.

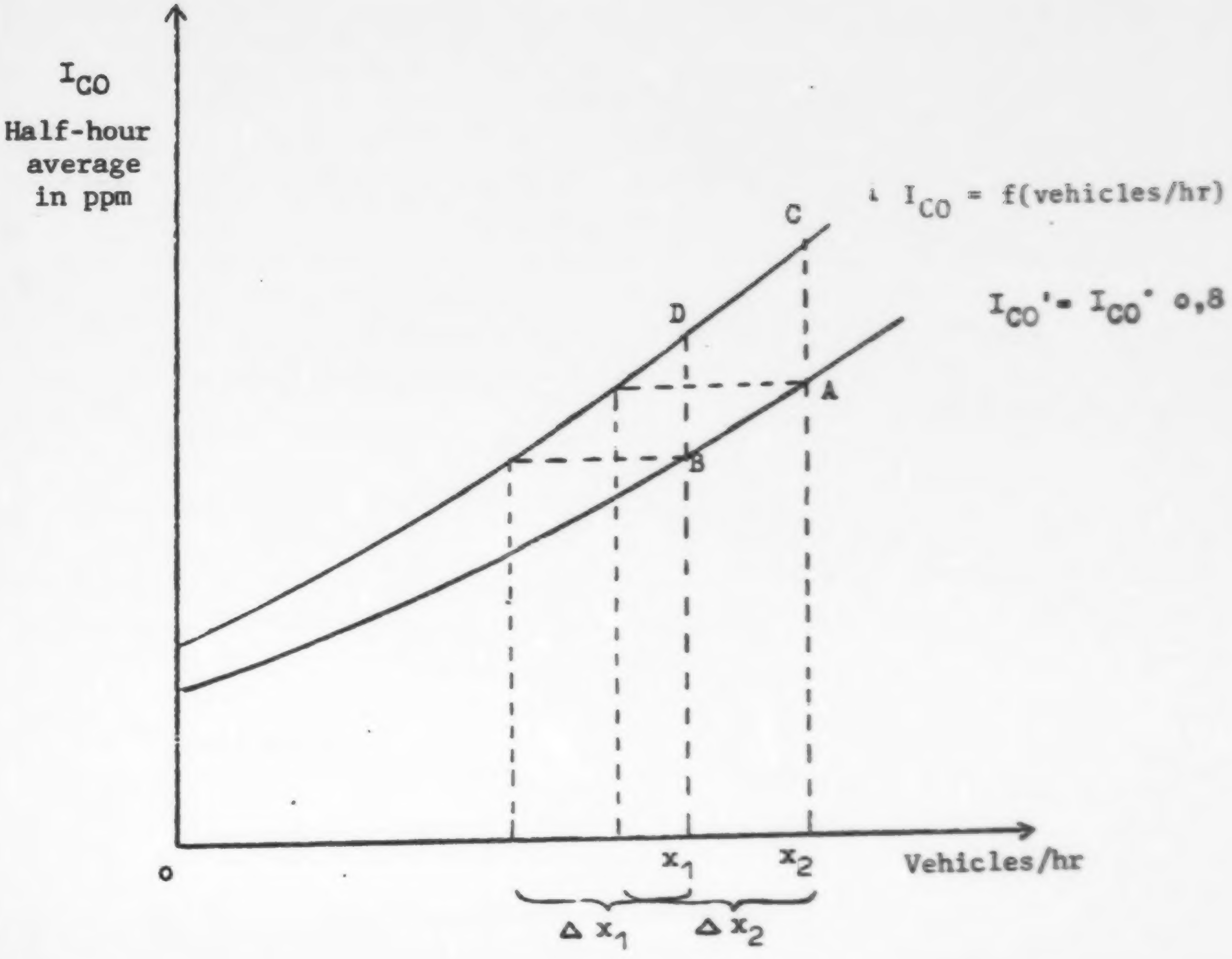

Figure 1. Immission function for the model block L_x.

$$n' = \frac{\ln I_{CO}' - a}{b} = \frac{2,57 - 1,2}{0,0011} = 1245 \text{ vehicles/hour}$$

Therefore, a reduction of the traffic volume from 1,600 to 1,245 vehicles/hour = 22% would be necessary in order to realize the target value, I_{CO}'. Every single one of the 1,600 vehicles/hour would have to reduce its emission by 22%. The procedure is shown graphically in Figure 1.

Assume the function I_{CO} = f (vehicles/hour) shown for the model block L_x. Empirical immission measurements on a certain day in metropolitan Cologne, represented in the model by the model block, L_x, have given a 24-hour average of 10 ppm. This requires a 20% reduction of all the CO half-hour averages.

This reduction would replace the I_{CO} function with $I_{CO}' = I_{CO} \cdot 0.8$. In order to determine the emission decreases per vehicle with which the target immission values are obtainable, we enter the diagram with the actual traffic volumes, x_1, x_2. It appears that the immission objective at site x_2 (= A) can be attained only by decreasing the traffic volume by Δx_2 (in %) or on the basis of the proportionality hypothesis, in which the emissions of each vehicle in the traffic volume, x_2, are improved by the same percentage (Δx_2 in %).

In this way, then, we can to a first approximation obtain a connection between immission and emission. Depending on the position and slope of the basic immission function, we can also calculate different reduction ratios by this method. In this work, for instance, we obtained an average of 30 traffic volume values per measuring day, and, then, 30 values for reduction ratios. But for political activities we must assume that all vehicles on the average reduce their emissions by the same ratio. But, out of the 30 values determined, which one do we establish as binding for political decisions? If one were to equip all vehicles for the highest ratio calculated, then the goal of attaining a 24-hour average of 8 ppm would be more than achieved; but it would not be attained using the smallest value as a basis. Thus, practical averaging is advised. A simple arithmetic mean of the reduction ratios determined appears as the first approximation. (It remains to be tested whether weighting of the individual values with the matching traffic volumes or I_{CO}' values would turn out to be more suitable.) The result found in this way must be interpreted as follows: If the prescribed 24-hour average for the CO immission is not to be exceeded in an actual situation, then for the traffic volume met on measuring day y, this assumes that the emissions of all the vehicles passing measuring site y have been reduced by the average percentage determined. Varying traffic parameters (especially the traffic volume) would lead to another average emission reduction ratio, and also to a different necessary relative immission reduction. A more representative result can be attained here only through considerably more extensive measuring programs over longer periods.

One limitation of this method arises from the basic immission load at zero traffic volume, which is represented by the term e^a in the equation. According to the interpretation of the Rhineland Technical Monitoring Union working group, this is a CO immission which is dependent on street traffic, but which is produced by traffic in other streets. This makes the procedure described here more difficult, inasmuch as no reasonable statements about the necessary reduction of the traffic volume are any longer possible for all the I_{CO}' values which are smaller than I_{CO} at site 0. The higher this basic load and the flatter the curve of the immission function, the more serious this deficiency is. Immission loads from source A cannot be changed, no matter how strong the reducing measures at source B. The effect has a reducing action on the averaging because the reduction ratios determined become greater with increasing nearness to the coordinate origin. This fact agrees well with the explanation introduced elsewhere. One would load the emitters of source B with higher reductions than would be given from their own contribution to the immission. This deficiency is less serious than it appears at first glance. The portion of the immission function in this lower range has arisen from extrapolation of the function, to the extent that it cannot be defined distinctly here. The definition ranges of the immission functions are given in Table 8 on page 46 of the Technical Monitoring Union report. Furthermore, if one interprets the inner city street net, analogously, as a system of communicating tubes, then with a low traffic volume in one street (assuming we are not dealing with the effects of bypasses) we can also assume similar conditions in the other streets. But this means that the basic load for a traffic volume of zero approaches zero. With this, the immission function would behave differently and the problem mentioned above is for the most part eliminated in any case.

One further premise should be mentioned here. The proportionality hypothesis applies only so long as the mode remains constant. In reality, this prerequisite is provided only in part, or not at all. In the normal case, the driving speed, which determines the mode, also changes with a varying amount of traffic. With increasing traffic volume this leads to congestion and greater emissions per unit distance. This process is in itself continuous. For simplicity, the Rhineland Technical Monitoring Union working group classified it into the so-called driving modes, in which one driving mode includes

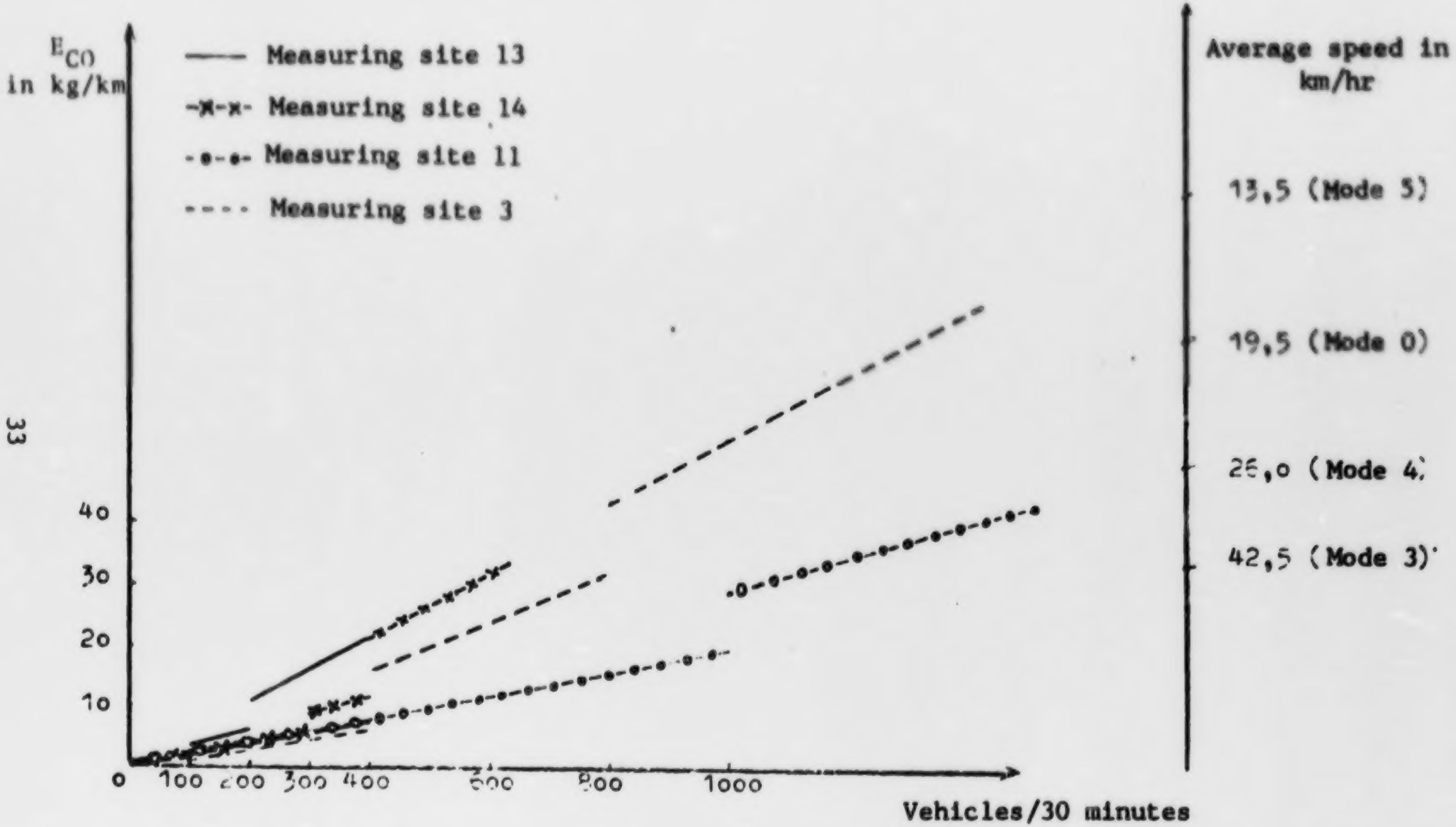

Figure 2. Driving mode as a function of traffic volume for some Cologne measuring sites.

a whole range of speeds [1]. The immission functions obtained empirically through regression of emission and traffic volume data probably take the continuous change of speed, or the effect of traffic, into consideration. Thus, if a reduction of traffic volume by 20%, for instance, is determined using the immission function in the form described above, this is only 20% because the reduction has also improved the driving mode. On the other hand, it would be conceivable that with the same amount of traffic and, then, the same mode, this same percentage emission reduction of 20% on the individual vehicles might not have the same effect; it would probably have to be somewhat greater. This relation does not yet allow exact quantification; but it can be conjectured that the emission reductions for individual vehicles determined by means of the proportionality relation are somewhat too low.

B. On the Results

1. Application of the Specified Immission Functions

Analogous to the method described above, the following calculations were done:

The long-term limit for CO (24 hour average) of 8 ppm was exceeded on 14 measuring days for measuring point 5 (0.75 m above the edge of the sidewalk) (measuring sites 3, 4, 5, 6, 8, 9, 10, 14) in the empirical immission measurements in metropolitan Cologne. Measuring site 8 was not accessible for the calculations described here, because there are no specific immission functions for it. Next, the excesses over the limiting value were determined for the particular measuring day, and with this, the necessary relative immission reductions in % (see Table 1).

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(1) This relation can be represented graphically for some Cologne measuring sites (see Figure 2).

In order to determine the resulting requirements on the emission side, the specified immission functions were used in a first pass. These functions were worked out by the Rhineland Technical Monitoring Union for model blocks 1, 2, and 4 in dependence on meteorological differentiations. These functions are differentiated by three wind direction classes (upwind, downwind and wind in the direction of the street, where upwind and downwind refer to the site of the measuring instrument) and three wind speed classes (0 - 3 m/s, > 3 m/s, and without differentiation).

With sufficient information on the relations, it would naturally be suitable to use for analysis of the measurement and traffic data for a certain measuring day the immission function derived for the meteorological data of that day. But that would assume that with changing meteorological data on the measuring day, theoretically, in the extreme case, a different function should be applied for each weather condition on this day. It remains undecided whether consideration of the prevailing weather situation is sufficient. The method used here is sufficiently accurate, as shown by the relative agreement of the average of the ratios obtained with the specified functions with the ratios obtained from the general functions (see Table 3). For this reason, the traffic volume data for each measuring site were confronted with all variants of the immission function valid for the measuring site in question (assignment of the measuring site to a certain model block). This considerably increased the computing cost, especially because all variants, 9 functions, had to be calculated for model block 1, to which 2 measuring sites were assigned on 3 measuring days. As an example, we may mention site 5 on 15 November 1971. The necessary immission reduction is 10%. The functions for model block 1 apply for this measuring site. Of the 9 functions, $I_{CO} = d^a \cdot e^{bn'}$, only the target function was determined first: $I_{CO}' = e^a \cdot e^{bn'} \cdot 0.9$. By using this target function, and inserting the number of vehicles per hour for n', the corresponding I_{CO}' values could be found. As a rule, there are about 30 traffic volume values in vehicles per 30 minutes available per measuring day. These can be doubled to convert them to vehicles/hour. Now, in order to determine the traffic volume which would give the desired immission reduction, the function $I_{CO}' = e^a . e^{bn'}$ was solved for n':

$$n' = \frac{\ln I_{CO}' - a}{b} .$$

Thus, if one had determined the corresponding I_{CO}' values for the 30 traffic volume values, then with the formula above one could relatively easily determine the traffic reduction. For measuring site 5 of 15 November 1971 we obtained, accordingly, 9 times 30 reduction ratios, which are shown as 9 arithmetic averages for the individual function types.

We acted analogously for all the other measuring sites and days. Here, some quantitative limitations were possible, as there are only 3 functional variants for model block 4 and only 5 for model block 2. The numerical results of this calculation are shown in Table 1. They require interpretation:

The necessary percentage emission reductions vary between 13.1 and 84.7%. (The five values which are even higher were shown only for completeness and marked with a +. They were determined from too few measurements to have predictive value.) What explanations are possible for this great range of variation in the results?

Table 1. RELATIVE EMISSION REDUCTION RATIOS IN % FOR CO FOR THE INDIVIDUAL MEASURING DAYS (LONG TERM VALUES), DETERMINED USING THE SPECIFIED IMMISSION FUNCTIONS (MEASURING POINT 5)

Measuring site	Date of measurement	Assignment to model block	24-hour average determined in ppm	Required immission reduction in %	Meteorological parameters for the functions					
					Wind direction	Upwind	Upwind	Upwind	in street direction	in street direction
					Wind speed	> 3 m/s	Total	0-3 m/s	> 3 m/s	Total
3	4.11.71	4	11,7	32				91,6 +		
4	8.11.71	2	11,2	29		30,4	44,2		84,7	22,5
5	15.11.71	1	8,9	10		41,7	38	38,1	44	39,4
6	3.12.71	4	18,4	57				0		
	15.6 72	4	8,7	8				37		
	13 7. 72	4	10,5	24				90 +		
	14.7 72	4	10,3	22				86 +		
9	20.12.71	1	10,3	22		27,8	26,1	22,5	22	21,3
	21.12.71	1	11,6	31		34,3	32,4	28,7	37,7	27,9
10	1.12.71	2	13,2	39		95 +	0		0	74
	2.12.71	2	12,4	35		88 +	0		0	65
14	18 11.71	4	8,2	2				22,3		
	19.11.71	4	8,9	10				45,8		

o No statement possible, as I_{CO}' at the greatest traffic volume $< I_{CO}$ at zero traffic.

+ Determined from only a few values (maximum 13)

UCTION RATIOS IN % FOR CO FOR THE
DAYS (LONG TERM VALUES), DETERMINED
MMISSION FUNCTIONS (MEASURING POINT 5)

r ge ned	Required immission reduction in %	Meteorological parameters for the functions used									
		Wind direction	Upwind	Upwind	Upwind	in street direction	in street direction	in street direction	Down-wind	down-wind	Downwind
		Wind speed	> 3 m/s	Total	0-3 m/s	> 3 m/s	Total	0-3 m/s	>3 m/s	Total	0-3 m/s
	32				91,6 $^{+}$			74,4			28,7
	29		30,4	44,2		84,7	22,5	18,8			
	10		41,7	38	38,1	44	39,4	31,2	58	29,3	24,6
	57				0			0			72
	8				37			28			9
	24				90 $^{+}$			79			33
	22				86 $^{+}$			73			39,6
	22		27,8	26,1	22,5	22	21,3	15,3	39,9	16,9	12,6
	31		34,3	32,4	28,7	37,7	27,9	23,1	52,1	22,3	17,7
	39		95 $^{+}$	0		0	74	57,5			
	35		88 $^{+}$	0		0	65	48,5			
	2				22,3			15,0			14,3
	10				45,8			31,5			13,1

I_{CO}' at the greatest traffic volume

values (maximum 13)

The following regular tendencies can be detected for the immission functions determined through regression:

- the correlation coefficient for the downwind measurement (the measuring equipment is in the wind shadow) tends to be higher than in the upwind measurement.
- as a rule, the correlation coefficient is highest for the values measured at the lower wind speeds.

Furthermore, the greater the slope of the function, indicating a higher regression coefficient, the greater is the effect of a variation in traffic volume on the immission situation. At first glance, measuring sites described by a steeper function appear to be "more dangerous" from the standpoint of environmental damage. But if one considers the relation from the emission side, especially from the viewpoint of expense and results, then it describes the happy circumstance that the immission can be affected strongly with relatively low expense on the emission side. We shall have to go into this relation again in the treatment of the short-term values. This "superproportionality" also becomes very distinct in the results. For example, for site 9 on 21 December 1971, for a required immission reduction of 31%, using the function for downwind and wind speed 0 - 3 m/s: $I_{CO} = e^{0.8} \cdot e^{0.0035\, n'}$, we calculate that the necessary reduction in traffic volume or emission is only 17.7%.

Site 5, for 15 November 1971, can serve as a counter-example. The required immission reduction for this measuring day would be 10%. For the function downwind, wind speed > 3 m/s: $I_{CO} = e^{1.6} \cdot e^{0.0001\, n'}$, we calculate an emission reduction of 58%, although we are dealing with a downwind situation (1).

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(1) See the discussion on page 35 ff on the variations of the immission functions which should be used.

In spite of all reservations, this may be an indication that the wind speed is a factor with greater weight than the wind direction.

The highest reduction ratio calculated anywhere, 84.7% (measuring site 4, 8 November 1971, model block 2), also occurred in the highest wind speed class, with the wind in the direction of the street. The basic immission is very flat: $I_{CO} = e^{2,3} \cdot e^{0,001\,n'}$ and also shows a very high basic load of 9.97 ppm. This functional type also gives relatively high emission reduction requirements for other measuring sites (site 5 for 15 November 1971 and site 9 for 21 December 1971).

Finally, we must mention the quantities marked with a 0. Here, application of the corresponding model was not possible because even at the greatest traffic volume recorded at those measuring sites, the I_{CO}' value was smaller than the basic immission load at a traffic volume of 0 vehicles/hour. This is expressed mathematically by saying that $\ln I_{CO}' < a$,

so that the numerator becomes negative: $n' = \frac{\ln I_{CO}' - a}{b} < 0$. As mentioned briefly at the beginning, a further weakness of the method becomes apparent here, and it should be considered for the interpretation of the results presented. The fields characterized by 0 would have been filled by emission reduction ratios if the empirically observed traffic volume has exceeded the point at which $I_{CO}' = e^{a}$ or $\ln I_{CO}' = a$.

Here, we must once more make it plain that a shift of the traffic volume spectrum to another order of magnitude (greater traffic volume) tends to reduce the average value. The tendency of the concrete effects cannot be evaluated here, because the new immission situation occurring with greater traffic volumes probably would also have affected the regression and with it, the immission function itself. As emission reductions on the vehicle are tied to significant costs, we must select or determine, out of the many reduction ratios presented, those with the highest efficiency, without violating the medical requirements. But such an efficiency analysis is possible only if information is available about the damages prevented by certain avoidance measures. For the present we can decide only purely pragmatically what order of magnitude to consider somewhat reasonable, in view of the relatively small empirical basis and the weaknesses no doubt present in the procedure. As an important argument, we must consider the medical objection that for the evaluation of the harmfulness it is not so much a matter of how often a limit is exceeded, but much more the fact that it is exceeded. As one must in principle work on the basis that for each vehicle the probability of passing a certain measuring site is equally great, this would mean improving the entire vehicle population by 84.7% with respect to emissions (Point 5 of 11/15/71). This is linked with enormous cost. It does not appear justified to draw a conclusion with such serious consequences from the measurements of one day and one measuring point, although in the individual case, results of such an order of magnitude appear possible throughout, depending on the pattern of traffic volume data and meteorological parameters.

In order to expand the fundamental base, we determined a simple arithmetic mean from the 50 calculated reduction ratios. This gives an emission reduction of 36.9%. Even if an orientation to this order of magnitude would mean that the worst situations would not be improved sufficiently, we could obtain a considerable effect on the immission situation. Here again, of course, the question arises of whether simple averaging adequately takes the objective into consideration. For instance, it would be conceivable to weight the figures with the required relative immission reduction in each case.

Then emission reductions would be weighted more in the cases where the limits were exceeded farther. Here, the physicians must help in the decision.

It would also be conceivable to weight the figures with the relative proportions of the model blocks in the whole city. This could take into consideration the point that actual construction situations which occur only rarely in the city would have low weight in the environmental evaluation. For instance, the model blocks 1, 2, and 4 which were applicable here have the following proportions on the inner city street net, according to the data of Dr. Glück:

L_1 = 22%
L_2 = 20%
L_4 = 0.6%

Models 1 and 2 then would cover a relatively large area.

2. Application of the General Immission Functions

Along with the selected immission functions, specified from the meteorological viewpoint, there are 5 functions available which avoid this differentiation and which are valid for the corresponding model block in all weather conditions. Emission reduction ratios were also determined by the same method for these functions. Admittedly, the number of ratios determined was correspondingly lower, because there is only one basic function for each measuring day. The results are shown in Table 2. For comparison, Table 2a shows the values which appeared for the long-term excesses of the values for the other measuring points. Here it becomes clear that even an evaluation using the other measuring points will not significantly change the required emission reduction ratios.

The average of 36% for measuring point 5 is compared with 44% (point 1), 40% (point 2), 46% (point 4) and 37% (point 6). If we consider that there are spreads of about 5% above and below for the reduction stages, then all the reduction ratios for the different measuring points could be realized with about the same expense.

A comparison with the results of the specified functions provides some interesting disclosures:

a) Agreement can be established in the results to the extent that part of the ratios obtained with the general functions for the individual measuring days agree with the arithmetic averages of the portions determined with different specified functions for the corresponding measuring days, at least in order of magnitude (see Table 3). This relative agreement somewhat weakens the objection that only those specified functions can be used which show the same meteorological functions as the corresponding measuring days.

b) Finally, let us compare three more averages. The simple average of the necessary immission reductions is 24%. The average of the emission reduction ratios calculated with specified functions (a total of 52 values, not including those marked with $^+$) is 36%. The arithmetic average of the emission reductions of the general functions is 36% without the extreme value of 93^+. Inclusion of the extreme values would give 41% (57 values from the specified functions) and 41% from the general functions. In spite of the quantitative limitations of the basic data, this gives a preliminary indication that a somewhat superproportional emission reduction is needed in order to maintain the medically specified immission limits.

Table 2. RELATIVE EMISSION REDUCTION RATIOS FOR CO FOR THE INDIVIDUAL MEASURING DAYS (LONG TERM VALUES) DETERMINED USING THE GENERAL IMMISSION FUNCTIONS (MEASURING POINT 5).

Measuring site	Date	Assignment to model block	24-hour average in ppm	Required immission reduction in %	Emission reduction determined, in %
3	4.11.71	4	11,7	32	51,5
4	8.11.71	2	11,2	29	50,7
5	15.11.71	1	8,9	10	29,3
6	3.12.71	4	18,4	57	93 +
	15. 6.72	4	8,7	8	17,8
	13. 7.72	4	10,5	24	62,6
	14. 7.72	4	10,3	22	64,7
8	22.12.71	10	9,3	14	11
9	20.12.71	1	10,3	22	17,1
	21.12.71	1	10,6	31	26,3
10	1.12.71	2	13,2	39	o
	2.12.71	2	12,4	35	o
14	18.11.71	4	8,2	2	16,4
	19.11.71	4	8,9	10	24,6

+ Only one value

o The general immission functions are not applicable. With the measured traffic volumes, reduction of the traffic volume to the negative range would be needed.

Table 2a. RELATIVE EMISSION REDUCTION RATIOS FOR CO FOR THE INDIVIDUAL MEASURING DAYS (LONG TERM VALUES) DETERMINED USING THE GENERAL IMMISSION FUNCTIONS (MEASURING POINTS 1, 2, 4 and 6).

Measuring site	Date	Model - block	24-hour average - in ppm				Required immission reduction in %				Calculated CO emission reduction ratios in %			
			Measuring point				Measuring point				Measuring point			
			1	2	4	6	1	2	4	6	1	2	4	6
2	4.11.71	4	10,3	11,3	10,5	11,4	27	29	22	30	39,5	43	32	56,6
[illegible]	5.11.71	2	9,3	8,[illegible]	7,[illegible]	[illegible]	14	2	-	26	21,6	5,4	-	46,9
6	3.12.71	4	15,5	14,0	[illegible]	16,8	45	43	37	52	85,1	73,9	70,7	97*
6	15. 6.72	4	7,4	8,4	6,8	5,5	-	5	-	6	-	3,8	-	14,6
[illegible]	13. 7.72	4	10,3	9,3	9,0	10,[illegible]	22	14	14	26	53,9	24,5	30,2	76,4
6	14. 7.72	4	9,4	8,9	9,[illegible]	9,7	15	10	18	13	41,9	26,3	45,6	57,8
3	22.12.71	10	6,3	6,1	5,0	9,5	-	-	-	16	-	-	-	27,3
2	20.12.71	1	7,8	6,3	5,9	5,5	-	-	-	6	-	-	-	7,2
[illegible]	[illegible].12.71	1	[illegible]	9,3	[illegible]	[illegible]	12	14	-	10	20,7	14,9	-	9,4
[illegible]	1.12.71	2	11,9	10,8	[illegible]	13,0	27	26	30	39	85,9	70,9	82,9	0
[illegible]	2.12.71	2	10,8	11,3	9,[illegible]	11,7	26	29	17	32	83,0	86,1	43,9	0
[illegible]	15.11.71	4	7,9	7,7	[illegible]	9,2	-	-	5	14	-	-	9,8	35,5
			Average								[illegible]	40	46	37

* Only one value

0 The functions are not applicable here; they would give reductions into the negative region.

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Table 3. COMPARISON OF THE AVERAGES OF THE REDUCTION RATIOS DETERMINED USING THE SPECIFIED FUNCTIONS WITH THE RESULTS FROM THE GENERAL FUNCTIONS.

Measuring Site	Date	Reduction ratios from using the general functions, in %	Average of the ratios from using the specific functions, in %
3	4.11.71	51,5	51,5
4	8.11.71	50,7	40,1
5	15.11.71	29,3	38,3
6	3.12.71	93 +	72 +
	15. 6.72	17,8	24,7
	13. 7.72	62,6	56
	14. 7.72	64,7	56,3
8	22.12.71	11	- +++
9	20.12.71	17,1	22,7
	21.12.71	26,3	30,7
10	1.12.71	o	75,5 ++
	2.12.71	o	67,2 ++
14	18.11.71	16,4	17,2
	19.11.71	24,6	30

+ only one value
++ three values
+++ only a general immission function was available for site 8.
o The general immission functions are not applicable because they would give reductions into the negative region.

The cost consequences from an emission improvement for CO on the individual vehicle, on the order of the 30 to 40% determined here, will be presented in connection with the treatment of the short-term average.

We must refer once more to the limitations:
The immission functions determined refer solely to CO, to measuring point 5, and to only part of the model blocks. They do not cover a series of actual inner city building situations.

II. ON THE ECONOMIC EVALUATION OF EXCEEDING THE HALF-HOUR AVERAGES.

From the empirical measurements of the Rhineland Technical Monitoring Union working group, 27 (measuring days) x 30 (half-hour measurements) x 5 (measuring points) = 4,050 half-hour averages for CO were calculated. Only 38 of these exceeded the limit (= 30 ppm). Here again we shall first analyze the values from measuring point 5, because both specific and general immission functions can be computed only with this one. For comparison, the excesses over the short-term values for the other measuring points (24 values) are also calculated with the general functions and shown in Table 6a. For 810 half-hour averages from measuring point 5 there were 14 which exceeded the limit.

Essentially, in treating the short-term values, we must also return to the proportionality relation between traffic volume and total emission, which was explained above. To be sure, the method is simplified inasmuch as the function I_{CO} = f(vehicles/hour) is explicitly available here for the half-hour averages, to which the limit refers. The small number of excesses over the limit, which are, of course, not accurately covered by the immission functions because these extreme points do not lie exactly on the curve of the function, indicates that in this chapter the description of the basic possible methodical procedure will have greater weight.

A. Methodology

1. Continuous Cost Curves

In a coordinate system with the function $I_{CO} = f(\text{vehicles/hr})$ a medically (or for other reasons) prescribed short-term limit is drawn as a parallel with the abscissa (see Figure 3, Quadrant I). Up to the point of intersection of the immission function with this line, no avoidance measures are necessary. But as soon as this value is exceeded, costs appear. They depend on the necessary degree of avoidance. Using the method for treating the long-term values as a basis, the required reduction in emission is determined through the relative reduction in the traffic volume. This process can be described by a function which has a "zero point" at the vehicle volume at which the immission limit is exceeded and which approaches the value of 100% asymptotically (see Figure 3). This function describes the percentage by which any traffic volume must be reduced so that the immission limit is not exceeded. The slope and course of this function are determined primarily by the initial level. For instance, if the immission limit is exceeded at a traffic volume of 100 vehicles/hour, then the "function of the relative traffic volume variations" reaches the value of 50% at 200 vehicles/hour, the value of 66 2/3% at 300 vehicles/hour, etc. It can, therefore, be stated immediately for any arbitrary type of immission function, as long as a limit is stated. In a first step, using these two functions, we can read out the avoidance costs as relative reductions in traffic volume or emission, for half-hour average excesses of the CO immission, in a continuous variation with the traffic load. Theoretically, it is also possible in this way to consider very small changes in the traffic volume down to one vehicle/hour. Later, we shall show how this statement must be modified for the practical form.

In order to transform these relative traffic volume or emission reductions into absolute cost quantities, a cost function is plotted in the second quadrant of the coordinate system. This describes the dependence of the avoidance costs per vehicle on the relative degree of reduction required (see Figure 4).

This cost function has different curves for the different types of motor vehicles. Unfortunately, an inquiry in this respect by the Rhineland Technical Monitoring Union working group in the German automobile industry was only partially successful, because part of the automobile manufacturers were unable or unwilling to make statements on the conjectured costs of alternative emission reduction stages. This, unfortunately, included manufacturers of those vehicles which determine the composition of the German vehicle population. The Institute based the avoidance costs considered in this study essentially on the values from manufacturer x. This was partly because this product was one which made up a significant proportion of the German vehicle population. It was also because the values agreed, at least in order of magnitude, with those in the literature for some reduction stages (see Table 8, appendix.). The values provided by two other manufacturers, by comparison, appeared less suited for this purpose because of the relatively small proportion of these models in the vehicle population in the German Federal Republic. For similar reasons, it did not appear very practical to take an average of these three values.

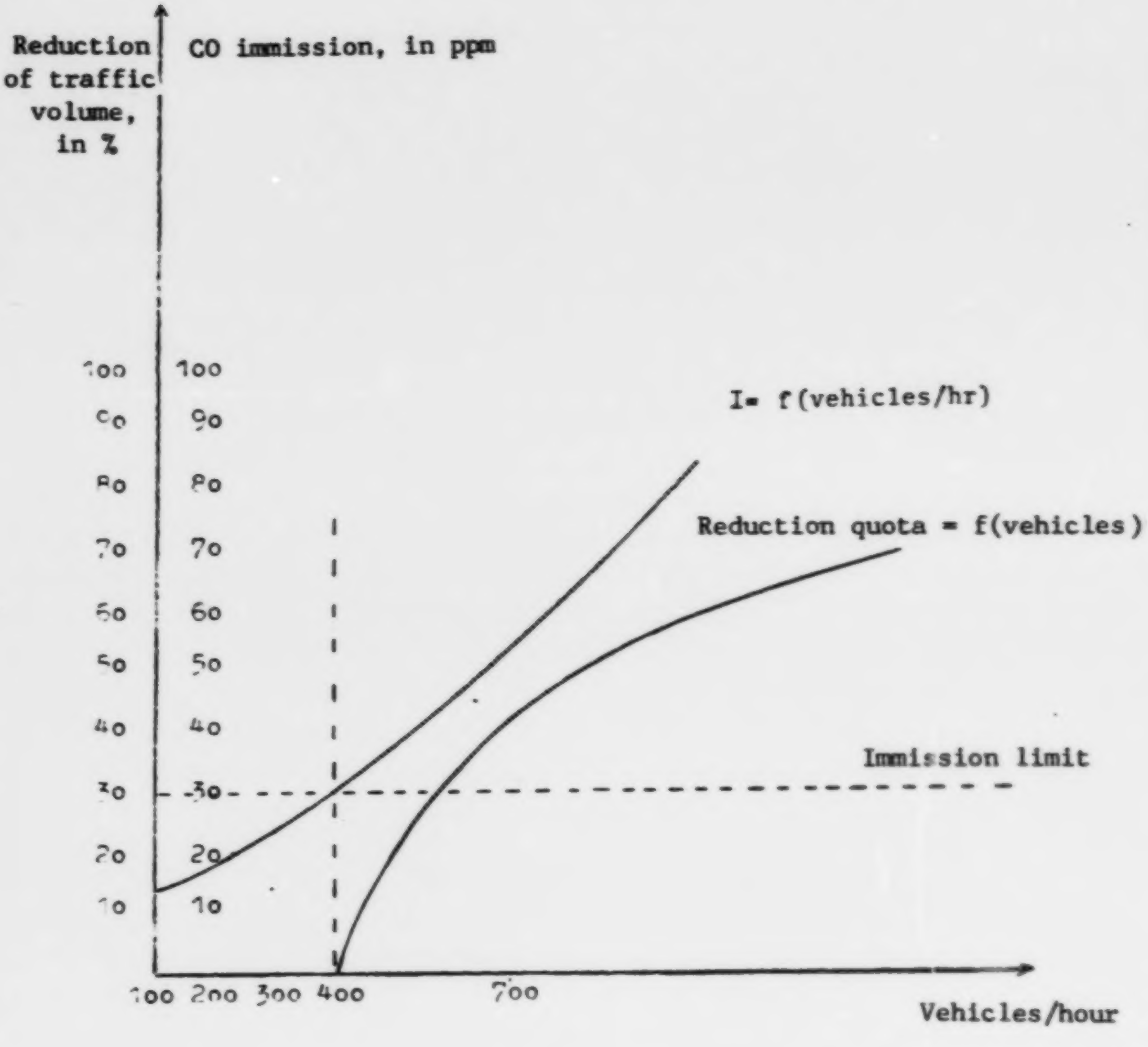

Figure 3. Immission function and dependence of the reduction ratio on the traffic volume.

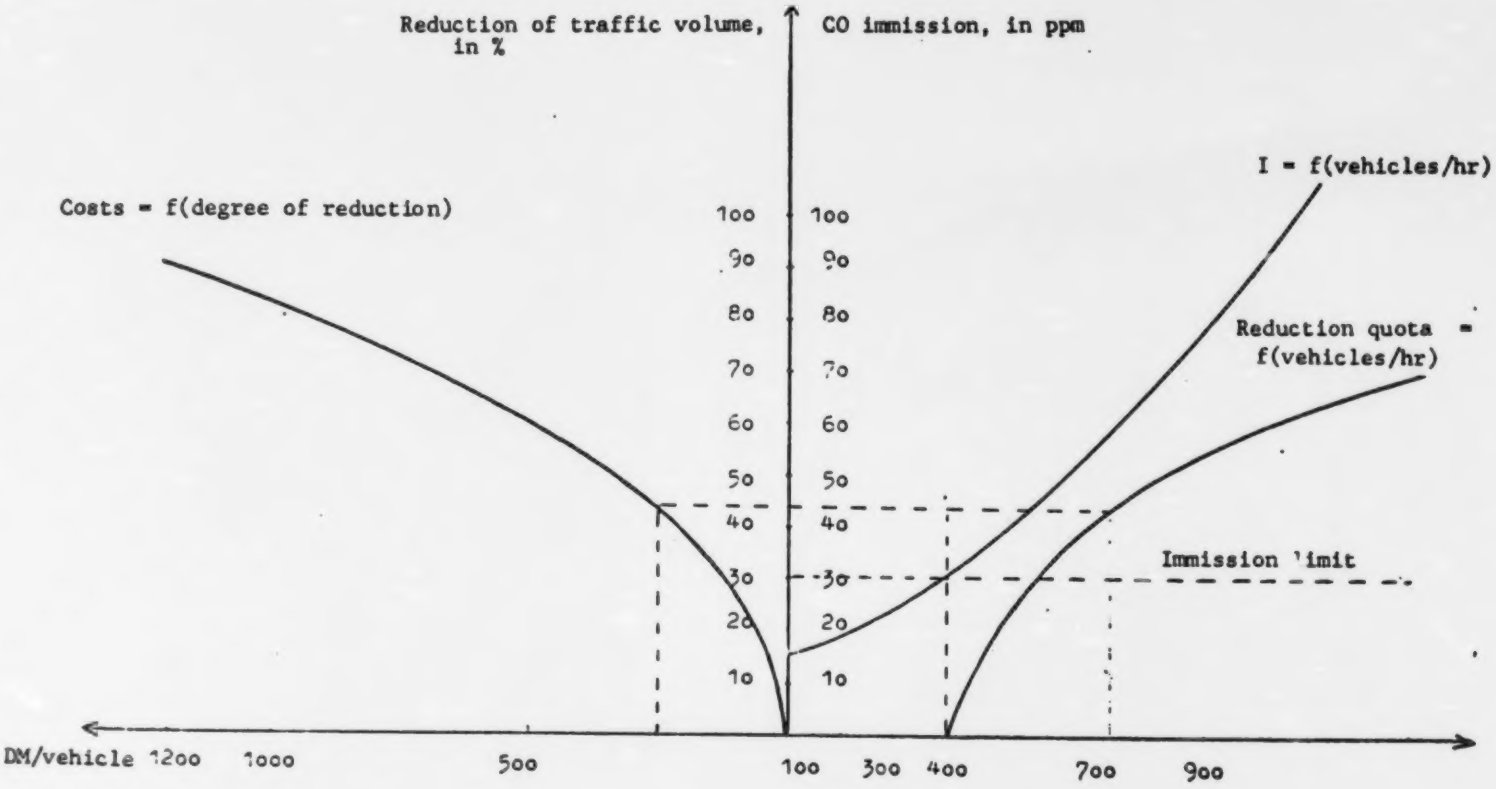

Figure 4. Avoidance costs as a function of the excess over the immission limit.

These three examples, however, make clear the great range of cost concepts, including the different judgement of the technical chance of realizing certain reduction stages. For instance, while two manufacturers gave different statements of manufacturing, operating and maintenance costs for a 90% reduction of CO, CH and NO_x, referred to the 1969 emission level, one manufacturer considers that no system is now available for a 90% reduction in the harmful materials.

Unfortunately, these data cannot be definitively interpreted with respect to costs. We mention here only the aspects of prototype-mass production, treatment as a design element integrated into the general production process or as a more or less independent replacement part or addition. The fact that an exact cost determination is difficult naturally arises also from the fact that many reduction requirements regrettably make necessary closer production tolerances (e. g., improvements in the carburetor), different engine designs (e. g., a better combustion space) and, finally, additional units (e. g., catalysts). These measures, moreover, mutually influence each other, or even exclude each other. There is another problem in cost calculation: individual measures which also, or perhaps even primarily, improve the emission behavior of the vehicle, also fulfil a series of non-emission-conditioned functions. For instance, what portion of the cost of an electronic fuel injection system should be allotted to emission improvement? Finally, in the interpretation of such cost data it should also be considered that they could in certain circumstances contain a portion which is not so much cost-oriented as market and sales-oriented.

These questions cannot be answered with the data now available.

Nevertheless, the generation of one or more cost functions in dependence on the reduction ratio appears basically possible. Literature references to a superproportional relation indicate that the costs will rise progressively with increasing degree of reduction (1) (see Figures 4a and 4b).

If such a cost function is found, then we can indirectly determine the absolute avoidance costs per vehicle for any arbitrary traffic volume.

Finally, the absolute costs in the third quadrant can also be compared directly with the traffic volume (Figure 5). Clear-cut boundary considerations are possible even here with a continuous curve for the function. The absolute avoidance cost for a few entering vehicles, and in the extreme case, one, can be determined as a difference quotient, $\frac{\Delta K}{\Delta M}$.

Before the modification of this representation by technical restrictions is described, we shall consider briefly the supposed relation between avoidance costs and actual damages. The method described here makes it clear that the same avoidance costs must be applied for different courses of the immission function at the same traffic volumes, as long as the limiting immission value is exceeded by the same amount of traffic (see Figure 6), independently of the absolute excess over the limit at the existing traffic volume.

Thus, the avoidance costs are the same for the traffic volume M for all three immission curves (= K), although at this site I_1 the limit is exceeded by 4 ppm, for example; at

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(1) See Heitland, H.: Problems of exhaust gas toxicity (cost-utility consideration) in VDA literature series, Volume 13,1972, page 67 ff; Dornier-System: Emission Reduction in Traffic, abridgement, Sept., 1972, Appendix, Figure 10.

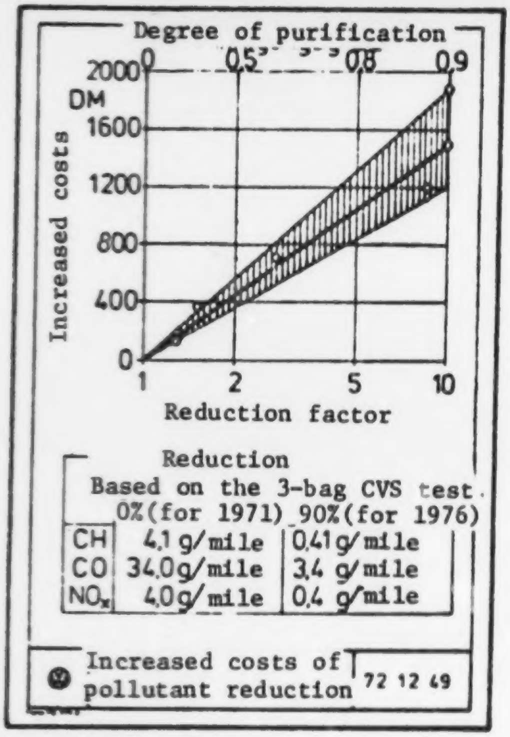

Figure 4a. Source: Heitland, H., . . . elsewhere, p. 68.

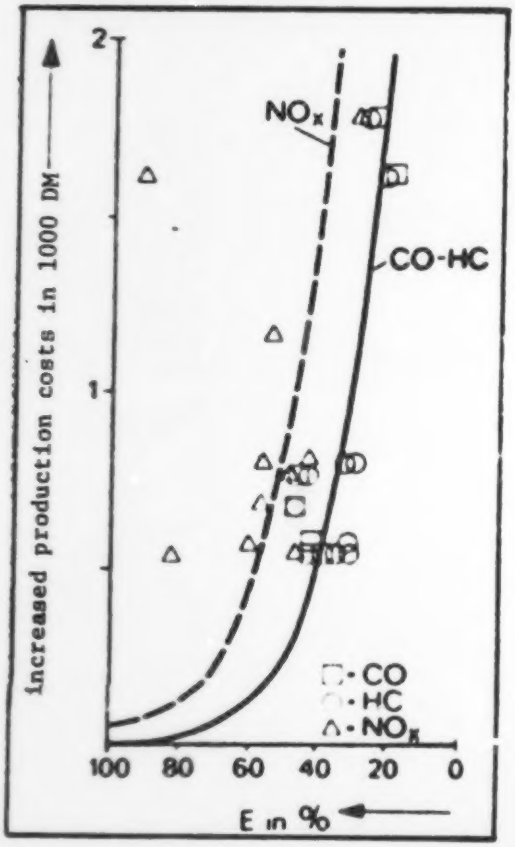

Figure 4b. Source: Dornier System, . . . elsewhere, Appendix, Figure 10.

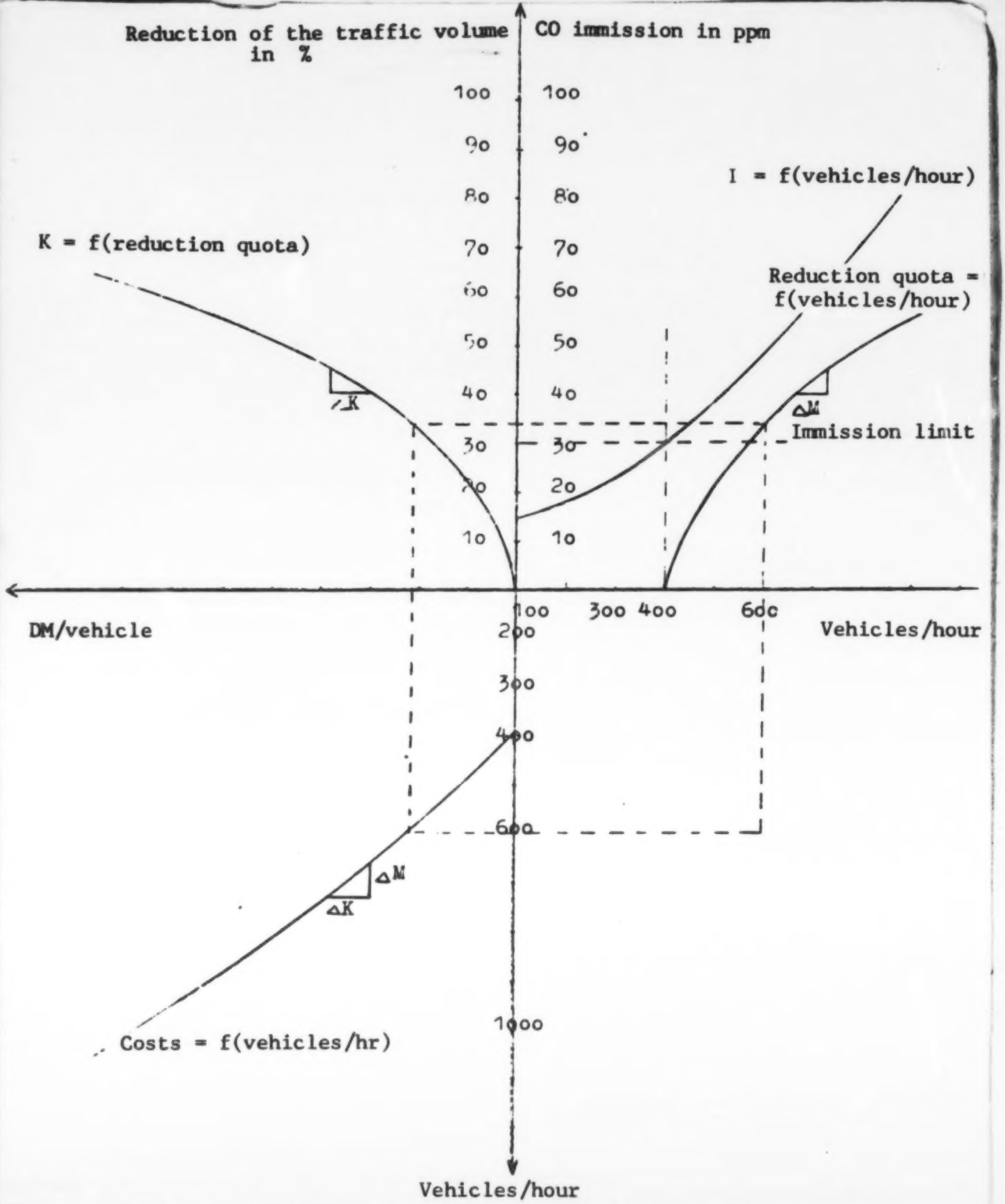

Figure 5. Avoidance costs as a function of the traffic volume.

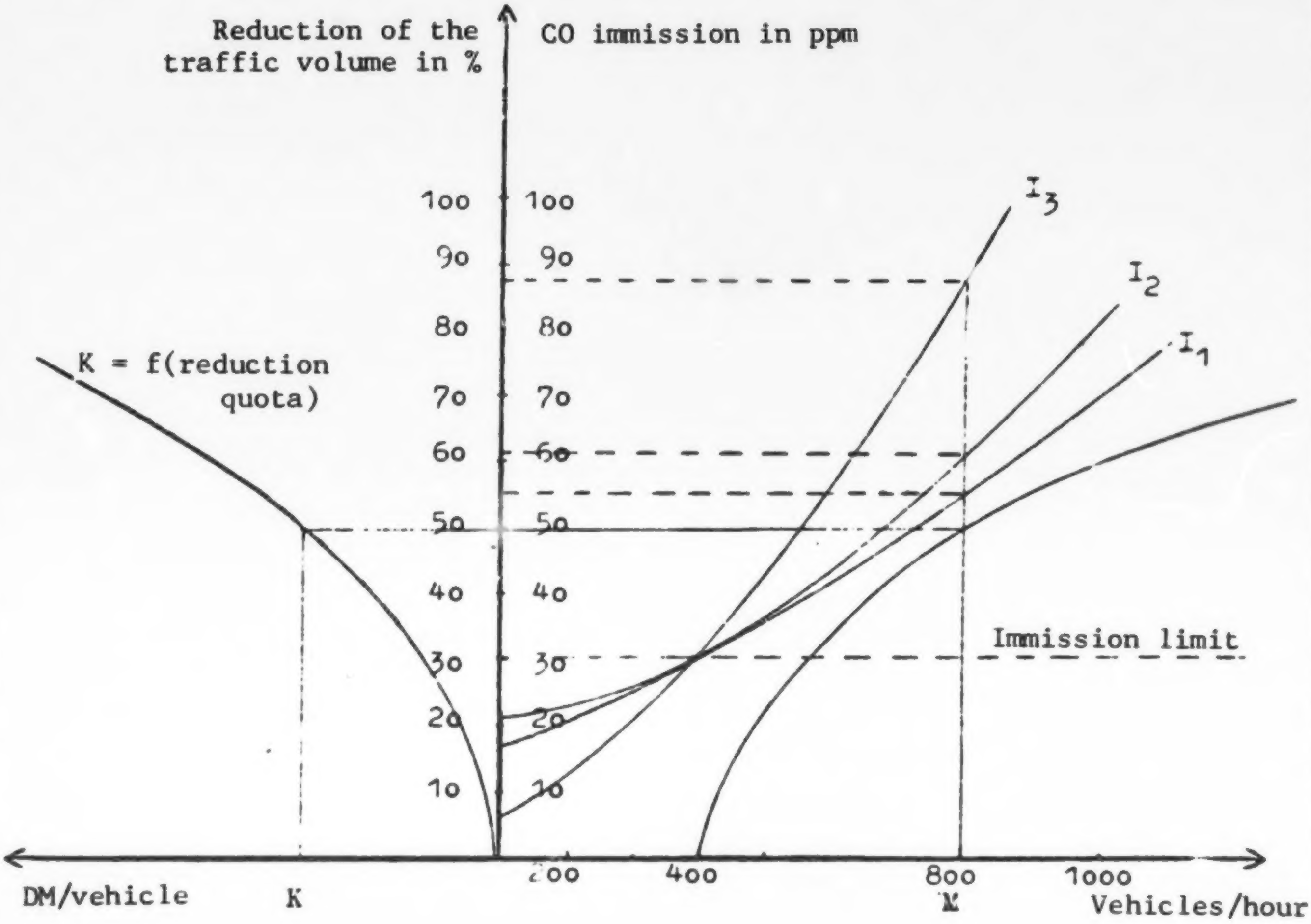

Figure 6. Identical avoidance costs with different excesses above the immission limit.

site I_1 by 11 ppm, and by as much as 38 ppm at I_3. On the contrary, it is probable that the direct damages (e. g., injuries to health) are greater, the greater the absolute excess over the limit is.

The explanation for this relation is simply that, as just explained for the treatment of the long-term value, a steeper immission function (e. g., I_3) gives a closer relation between CO immission and traffic volume. This says nothing more than that an improvement of the immission side can be gained with relatively minor avoidance action.

2. Discontinuous Cost Curves

Certain restrictions arise from the technical relation between emission-reducing measures and the reduction quotas, not so much for the principle, but for the representation. Emission reduction on the vehicle is impossible as a continuous process, or at least not economically reasonable. Instead, the reductions occur in large steps of some 10 or even 20%. All relative traffic volumes or emission reductions encompassed within one such interval must, then, be assigned to one cost quantity. On the basis of the questionnaire presented to the automobile manufacturers by the working group of the Rhineland Technical Monitoring Union, we assume the following reduction stages (see Table 4). These reduction stages are oriented to the environmental program of the federal government of 23 December 1971, in which there is a long-term attempt at reduction of the harmful components by 90%, referred to the average emissions for 1969 (see also the Technical Monitoring Union Report, page 58 ff).

Table 4.

Stage	Degree of Reduction +	
	CO + CH	NOX
1	20 %	-
2	40 %	30 %
3	60 %	60 %
4	80 %	80 %
5	90 %	90 %

+ referred to the initial emission level of 1969.

It is convenient to allow these intervals a certain range of some 5% upward and downward (1). The result of this is that, for instance, the required traffic volume or emission reductions from 1 to 25% would be assigned to the cost stage of 20%, and, correspondingly, 26-45% would be assigned to the cost stage 40%. (For the present we ignore the differentiation according to harmful materials.)

For the graphical presentation, this would mean that the cost functions would be in steps (see Figure 7). For a marginal consideration, another problem becomes particularly clear in this presentation. The increase of the reduction quota can be considered only to a limited extent in the additive form. That is, a change from 60% to 80% reduction requires the exchange of complete packages of measures. The marginal costs of the vehicle, for which the cost jump to the 80% stage was required at its appearance, include, to this extent, the total amount for 80%, and not the difference from the costs required for a 60% reduction, as would actually correspond to the difference concept in the marginal cost discussion. In contrast, such an additive relation may exist in certain ranges of the reduction band, where the reduction quota could be raised by a significant amount by certain additions to the technical equipment. Here the traditional way of considering the problem would be possible again for the marginal costs.

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(1) According to oral information from the Rhineland Technical Monitoring Union.

B. Empirical Results of Evaluation of Excesses of the Short-Term Average

Out of 810 half-hour averages at measuring point 5, 14 exceeded the medical limit of 30 ppm. They were analyzed in analogy with the long-term values.

First, every half-hour average which was > 30 ppm was tested with the specific CO immission function valid for the particular measuring site, and the necessary relative traffic volume or emission reduction was determined. For the 14 values discussed here, the functions for model blocks 2 and 4 were used. For all values which were analyzed with model 2 there were 5 reduction quotas, and 3 for the values analyzed with the immission functions of model block 4. Table 5 shows the results.

Then, similarly to the process with the long-term values, the general functions were used in a second computation without considering the different wind parameters. Naturally, only one reduction quota was calculated for each excess value (see Table 6 for the results.).

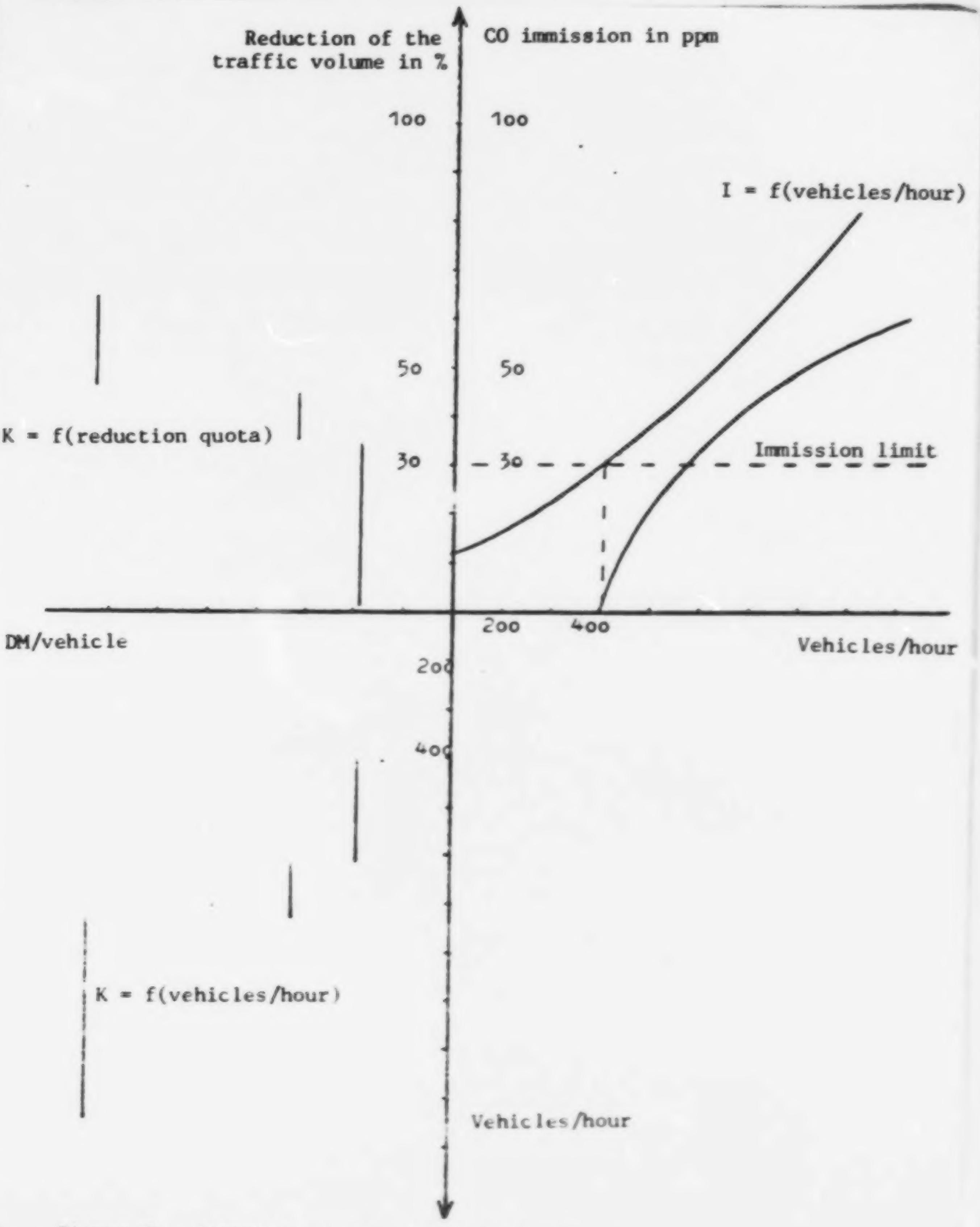

Figure 7. Stepwise course of the cost curves.

Table 5. RELATIVE REDUCTION QUOTAS IN % FOR CO FOR EXCESSES OVER THE SHORT TERM VALUES, DETERMINED USING THE SPECIFIC FUNCTIONS (MEASURING POINT 5).

Measuring site	Date	Model	Traffic volume in veh/hr.	Required emission reduction in %	Basic immission functions for the wind parameters							
					* 0-3 m/s	Upwind 0-3 m/s	Downwind 0-3 m/s	* 0-3 m/s	Upwind > 3 m/s	* > 3 m/s	**	* total
5	8.11.71	4	1687	21	16	32	10					
5	8.11.71	4	1687	22	41	63	17					
6	3.12.71	4	1040	6	14	22	9					
6	3.12.71	4	1313	6	12	18	7					
6	3.12.71	4	1177	6	11	17	5					
6	3.12.71	4	1080	19	41	62	15					
6	3.12.71	4	1017	17	47	71	19					
6	3.12.71	4	973	6	16	24	3					
6	3.12.71	4	1160	35	56	°	32					
10	1.12.71	2	770	6				4	11	42	17	°
10	1.12.71	2	557	32				32	69	°	58	44
10	1.12.71	2	807	38				45	89	°	°	59
10	2.12.71	2	633	12				8	23	76	24	16
10	2.12.71	2	757	6				2	11	41	26	8

° Functions cannot be applied because they give reductions into the negative region.

* Wind in street direction

** Upwind, wind total

Table 6. EMISSION REDUCTION QUOTAS IN % FOR CO FOR THE EXCESSES OVER THE SHORT TERM VALUES, DETERMINED WITH THE GENERAL IMMISSION FUNCTIONS (MEASURING POINT 5).

Measuring site	Date	Model block	Veh./hr.	Required immission reduction	Calculated Emission Reduction
10	1.12.71	2	770	6	18
10	1.12.71	2	857	32	54
10	1.12.71	2	807	38	-
10	2.12.71	2	833	12	39
10	2.12.71	2	757	6	19
3	4.11.71	4	1687	21	26
3	4.11.71	4	1487	22	30
6	3.12.71	4	1040	6	9
6	3.12.71	4	1313	6	8
6	3.12.71	4	1377	6	8
6	3.12.71	4	1160	35	66
6	3.12.71	4	1080	17	32
6	3.12.71	4	1017	17	33
6	3.12.71	4	973	6	-

Table 6a. EMISSION REDUCTION QUOTAS IN % FOR CO FOR THE EXCESSES OVER THE SHORT TERM VALUES, DETERMINED WITH THE GENERAL IMMISSION FUNCTIONS (MEASURING POINTS 1, 2, 4 and 6).

Meas. site	Date	Model	Meas. point	Veh./hr.	Concen. in ppm	Required immission reduction in %	Calculated emission reduction in %
3	4.11.71	4	1	1687	41,7	28	33
3	4.11.71	4	1	1487	35,3	15	18
3	4.11.71	4	2	1690	35,0	14	10
3	4.11.71	4	2	1687	51,8	42	48
3	4.11.71	4	2	1487	53,0	43	56
3	4.11.71	4	4	1687	39,0	23	26
3	4.11.71	4	4	1487	42,5	29	38
3	4.11.71	4	6	1687	37,2	19	24
3	4.11.71	4	6	1487	33,8	11	15
6	3.12.71	4	1	616	32	6	1
6	3.12.71	4	1	1160	32	6	1
6	3.12.71	4	1	973	32	6	3
6	3.12.71	4	6	1160	40	25	48
6	3.12.71	4	6	1017	32	6	10
10	1.12.71	2	1	807	32	6	12
10	1.12.71	2	2	807	32	6	18
10	1.12.71	2	4	857	32	6	12
10	1.12.71	2	4	807	40	25	64
10	1.12.71	2	6	600	32	6	27
10	1.12.71	2	6	857	32	6	17
10	1.12.71	2	6	807	48	37	negative
10	2.12.71	2	1	833	32	6	15
10	2.12.71	2	2	833	32	6	18
10	2.12.71	2	2	757	32	6	10

Here again, comparison of the results leads to some interesting statements. If one calculates an average from the reduction quotas determined with the specific functions for each excess value, then one can establish, similarly to the analysis of the long-term values, a relatively good agreement, in order of magnitude, with the values which were determined using the general immission functions for the particular excess value (see Table 7).

This relative agreement is also clear in a comparison of the averages of the reduction quotas from both routes of calculation. For measuring point 5, with the general functions it is 28.5% (1), and 31% for the specific functions. The average immission reduction required for the short-term values is 16.4%.

Similar relations also appeared between the required immission reduction and the average reduction quotas determined in the analysis of the long term values, although those were on a somewhat higher absolute level.

This relative agreement is the more satisfying because the objective as well as the maintenance of both the long and short term limiting values appear attainable with about the same expense on the emission side. In both cases the required reduction quota is of the order of magnitude of 30 to 40%. Even if this quota must be increased somewhat, due to the effects mentioned at the beginning, arising from the hypothesis of a constant driving mode, it appears from the existing information that improvement of the CO emission of the individual vehicle by an average of 40% would represent a sufficient improvement in the CO immission situation.

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(1) The average of the reduction quotas for the short-term excesses at the other measuring points (1, 2, 4 and 6), determined using the recalculated general immission functions (see Table 9 of partial study II 1.1) is 23% (see Table 6a).

Table 7. COMPARISON OF THE AVERAGES OF THE REDUCTION QUOTAS DETERMINED WITH THE SPECIFIC FUNCTIONS WITH THE RESULTS FROM THE GENERAL FUNCTIONS.

Measuring site	Date	Vehicles per hour	Emission reduction calculated with the general functions in %	Average of the quotas with the specific functions in %
10	1.12.71	770	18	14,8
10	1.12.71	857	54	61
10	1.12.71	807	-	64,3
10	2.12.71	833	39	31,4
10	2.12.71	757	19	15,6
3	4.11.71	1687	26	26
3	4.11.71	1487	30	41
6	3.12.71	1040	9	15
6	3.12.71	1313	8	12,3
6	3.12.71	1377	8	11
6	3.12.71	1160	66	64
6	3.12.71	1080	32	40,6
6	3.12.71	1017	33	45,6
6	3.12.71	973	-	14,3

Here it should be noted that these quotas which must be met in production will be sharpened somewhat for manufacturing, as the emission values for a large vehicle population vary about a mean. The mean which the manufacturer should meet must be considerably lower than the limiting value in production, so that the limit can be maintained for most cases (1) (see Figure 7a).

Furthermore, equipping the vehicle to attain the CO immission goal will automatically mean also an improvement for the other pollutants, CH and NO_x. The concept of the questionnaire to the automobile industry, for instance, assumes that the second reduction stage will lead not only to a 40% reduction of CO and CH but also to a 30% reduction of the NO_x emission. For greater reduction quotas, one should be warned that increased reduction in NO_x in particular is tied to strongly rising costs.

III. CONVERSION OF THE PERCENTAGE EMISSION REDUCTIONS INTO ABSOLUTE COST FIGURES

The data on the costs linked with the reduction requirements determined are still very incomplete. Figures from the international literature are of only limited help because it is difficult to compare them with each other. This is partially due to the different basic test driving cycles (California Test, EFZ). Furthermore, the percentage reduction quotas refer to different initial levels, etc. (see Table 8 in the appendix). The following considerations, therefore, are based essentially on the statements from one manufacturer in the German Federal Republic which makes up a large portion of the licensing statistics and covers a wide range of middle class types.(2) Three other sources are used for comparison and more detailed

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(1) In this respect, see Dornier-System, Emission reduction in traffic, cited elsewhere, page 13.

(2) The practicality has already been mentioned.

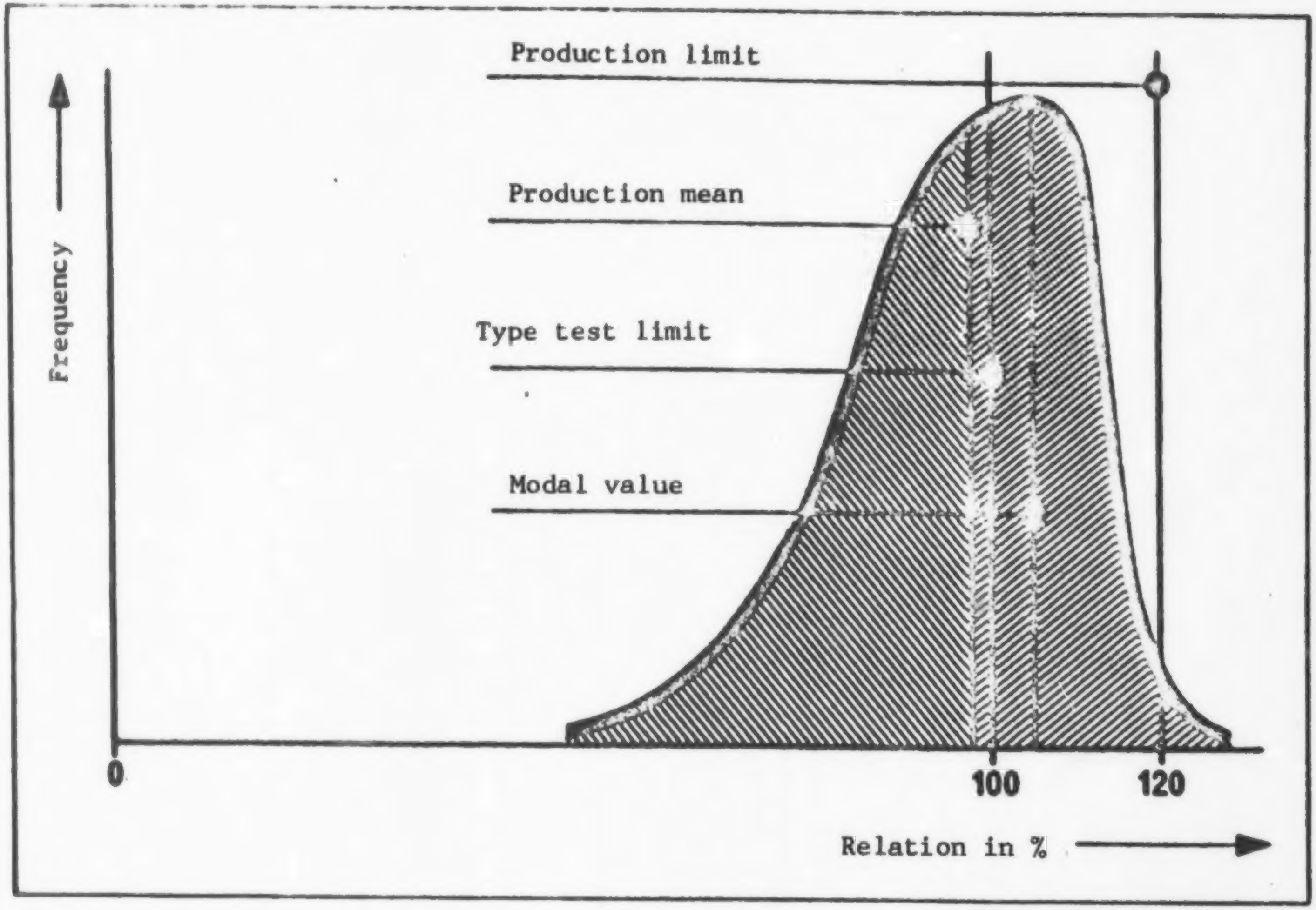

Figure 7a. Source: Dornier-System, . . . cited elsewhere, appendix, Figure 11.

interpretation. These include:

- the so-called RECAT Report (1) of 28 February, 1972
- a publication by Prof. Heitland (VW) included in the hope of finding information on the vehicle type which makes up the greater portion of the German automobile population (2)
- finally, data from a Dornier Study (3).

A. On Costs for Individual Vehicles

It is convenient to divide the increased costs which become necessary for certain reductions in pollutants into three categories. One category is the facility or investment cost for the collection or package of measures built into the vehicle. This is a one-time expense, granted that the lifetime of the emission-reducing measure is less than that of the car. In addition, there are continuous additional maintenance costs which can finally be ascribed to the emission-reducing measure. Finally, the engine economy is lowered by a series of installations to improve the exhaust gas. This is linked with added operating costs, especially with considerably greater fuel costs (see Table 8, in the appendix).

The costs estimated by the German automobile industry for these three types of costs are shown in Table 9.

The great range of variation between the types appear clearly from the table. For the investment costs, by way of comparison, we may once more refer to the estimates from VW and Dornier-System (see Figure 4a and 4b).

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(1) Final Report of the Ad Hoc Committee on the Cumulative Regulatory Effects on the Cost of Automotive Transportation (RECAT). Prepared for the Office of Science and Technology, 1972.

(2) Heitland, H., Problems of exhaust gas detoxication, . . . , cited elsewhere.

(3) Dornier-System, Emission reduction in traffic, cited elsewhere.

The low chance of realizing the high reduction quotas - especially for NO_x - reported in the Dornier study is striking. Finally, there is also an American value for the costs of a 90% pollutant reduction. It also agrees quite well with the VW value. The RECAT report states \$350 per vehicle for a 90% reduction, referred to the 1971 design year.

It was mentioned elsewhere that an exact economic interpretation of these data is very difficult. One argument for that was the prototype-mass production problem.

In the RECAT report mentioned above, an interesting attempt was made to determine, using two exponential functions, the technical progress in the period for manufacture as well as maintenance and operation of the emission-reducing measures. The functions have the following form:

$$I = 350 - 110\,(1 - e^{-0{,}33\,t})$$ for the investment costs

and

$$W = 65 - 20\,(1 - e^{-0{,}33\,t})$$ for the maintenance and operating costs.

For application of both functions to the value for manufacturer x and the VW value, the relative difference between the absolute term and the limiting value was made the same. This, for instance, gives the function:

$$I_{\text{manufacturer}\ x} = 80 - 25\,(1 - e^{0{,}33\,t}).$$

for the investment costs of a 30% reduction.

We proceed analogously with the function for the annual maintenance and operating costs, which includes both types of costs. It is clear that with cost-effective technical progress, the total expenses for the lifetime of a vehicle will

Table 9. INCREASED EXPENSES PER VEHICLE FOR MEASURES TO REDUCE EXHAUST GASES, DEPENDING ON THE DEGREE OF REDUCTION

Emission Reduction of the pollutants		Manufacture in DM/vehicle			Maintenance in DM/yr			Operation in DM/yr		
		Manufacturer			Manufacturer			Manufacturer		
CO + HC	NO_x	x	y	z	x	y	z	x	y	z
20 %+	-	80,-	10,-	50,-	20,-	-	50,-	-	-	-
40 %	30 %	160,-	40,-	100,-	60,-	10,-	50,-	100,-	70,-	100,-
60 %	60 %	600,-	150,-	300,-	80,-	300,-	100,-	250,-	110,-	200,-
80 %	80 %	1040,-	370,-	1200,-	500,-.	450,-	300,-	450,-	150,-	500,-
90 %	90 %	-	650,-	1400,-	-	600,-	300,-	-	200,-	500,-

+ For Manufacturer x this stage is 30%.

decrease with time (1).

The effect becomes clear if we compare a vehicle of the model year 1973 with one for 1982. A lifetime of 10 years is assumed for both behicles (2). The total costs (investment, maintenance and operating costs) for the reduction stages appear as follows:

Table 10.

1973 Model year	Reduction 30% CO	Reduction 80% CO, CH, NO_x
Investment cost	80,-- DM	1.040,-- DM
Maintenance and operation for 10 years	200,-- DM	9.500,-- DM
	280,-- DM	10.540,-- DM
1982 Model year		
Investment cost	56,25 DM	729,35 DM
Maintenance and operation for 10 years	143,-- DM	6.718,50 DM
	199,25 DM	7.447,85 DM

Table 11 shows the development of the investment, maintenance and operating costs per vehicle, considering the functions for technical progress.

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(1) These are based on 1972 prices. The possibility that the cost-reducing effect of technical progress will in reality be balanced by other price increases is not considered.

(2) The Federal Automobile Office in Flensburg estimates the average lifetime of a passenger car in the German Federal Republic as 9 to 10 years.

The additional costs which the autombile driver must spend due to requirements for reducing exhaust emissions can be assigned to only a certain part of his driving. It is only city driving which makes such measures necessary, if we ignore the fact that even emissions outside populated areas do not vanish without trace, but only reach non-dangerous concentrations, while,nevertheless,they are deposited in the global circulations of the load.

Therefore, in order to allot the costs to the actual causative factor of city driving, the total expenses per car and lifetime were apportioned per kilometer of city driving. We assumed an average lifetime of 9 years per car and an annual city driving of 5,000 km per vehicle (in this respect, see the report by Dr. Glück).

The functions for estimating technical progress were also considered for this calculation. For the emission reduction stage (30% for CO) determined from the Cologne measurements (the data from Manufacturer x were used as the basis for the 30-80% stages) the costs per vehicle per city kilometer driven are between 2.52 and 3.56 Dpf, depending on the state of technical progress (see Table 11a).

B. The Costs for the Entire Vehicle Population in the German Federal Republic

It became clear, in the analyses of both the long-term and short-term excesses over the limiting values, that in the system described here, boundary considerations are possible throughout in the sense that the addition of a few vehicles - even a single vehicle, in the theoretical limiting case - will increase the necessary reduction quota and, therefore, the avoidance costs. On the exhaust gas side, we consider solely active emission-reducing measures on the vehicle itself. We

Table IIa. ALLOTMENT OF THE TOTAL COSTS PER VEHICLE TO THE CITY KILOMETERS DRIVEN ([illegible] values from manufacturer X)

a) Costs per vehicle and lifetime (9 years) in DM

b) Costs per km driving distance in the inner city (based on annual inner city driving of 5,000 km per year), taking technical progress into consideration.
In Pfg. or Cents

[illegible]	Cost types	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
		a)	b)	a)	b)	a)	b)	a)	b)	a)	b)	a)	b)
[illegible]	Investment costs	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	[illegible]	[illegible]	
	Maintenance, repairs, operation	[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

73

Table [illegible]. INCREASED COST PER VEHICLE AS A FUNCTION OF THE DEGREE OF REDUCTION, CONSIDERING TECHNICAL PROGRESS, IN DM

Reduct. stage	Reduction of pollutant by CO, HC 30 %, NO$_x$ [illegible]		Reduction of pollutant by CO, HC 40 %, NO$_x$ 30 %		Reduction of pollutant by all materials, 60%		Reduction of pollutant by all materials, 80%		Reduction of pollutant by all materials 90%		
	M*	W+B**	M	W+B	M	W+B	M	W+B	M		W+B
[illegible]	22,--	20,--	160,--	160,--	600,--	350,--	1040,--	900,--	1500,--	370,--	65,--
1	19,--	18,50	146,--	14[illegible]	547,50	331,44	947,44	857,08	1358,12	319,20	59,40
2	18,--	17,12	136,--	13[illegible],40	509,70	281,64	885,64	800,56	1273,92	337,20	55,40
3	1[illegible],83	16,22	129,10	125,17	481,00	265,74	833,99	765,41	1203,27	282,70	52,40
4	16,78	15,68	123,50	11[illegible],23	462,76	256,54	801,29	736,11	1156,17	269,70	50,40
5	15,78	15,14	119,50	107,51	447,72	247,58	775,13	712,67	1118,44	260,50	48,80
6	15,58	14,2[illegible]	117,--	117,06	437,32	242,78	758,78	695,02	1094,04	255,40	47,80
7	1[illegible],18	14,60	115,--	11[illegible],20	430,60	238,70	745,70	686,50	1076,10	251,--	47,--
8	16,[illegible]	14,48	113,18	114,43	425,16	235,14	735,84	677,51	1061,97	247,72	46,40
9	15,83	14,50	112,10	113,43	421,40	233,10	725,72	671,64	1052,55	245,50	46,--
									VW	RECAT in $	RECAT in $

* M = manufacture

** W+B = Maintenance and operation

The values from Manufacturer 1 were used as the basis for Reduction stages from 30% to 80%.

ignore, here, such curious contrivances as gas masks and oxygen pumps in the city area, as well as city design activities which, for example, provide for better ventilation of the street canyons. Therefore, such a limit concept means that the increased emission reduction must in principle be performed for all the vehicles of a state. As has already been mentioned elsewhere, differential treatment of the vehicles does not seem practical. In the American RECAT report, to be sure, plausible concepts have been developed on a so-called "two-car strategy", primarily with the argument that a general legal emission reduction of 90% excessively charges those car owners who, because of their local use of the vehicle, do not contribute to negative environmental effects in the population centers. But the geographical conditions of the United States cannot be transferred to European and certainly not to German orders of magnitude. The vehicle density in cars/km^2 at which the RECAT report draws the boundary between requirement for reduction and no requirement is not reached in the German Federal Republic, even in the "outermost" thinly populated districts of the states of Bavaria and Schleswig-Holstein. However economically reasonable such a differentiation may seem from the viewpoint of efficient utilization of resources, this route does not seem passable for European conditions, quite aside from the question of whether the reported location of a vehicle gives sufficient conclusion about its local utilization intensity.

Uniform control, then, meansthat with rising reduction requirement,the whole vehicle poplation of a state must meet this requirement. This concept asumes that in theory every vehicle has the same chance to paticipate in the inner city street situation where exhaust gases are critical.

A second aspect which should be noted arises from the technical relationships. The statement of the proportionality hypothesis was that the relative reduction of the traffic volume would have the same effect on the immission situation as if each individual vehicle were improved by the same relative amount with respect to emissions, with an unchanged traffic volume.

But not all the vehicles in the traffic flow show the same emission parameters. Likewise, the possibilities of reduction for the individual types seem to be different, as a glance at the reduction cost tables for the different manufacturers makes clear. It would be natural, then, to classify the reduction quotas so that different reductions would be required from different types. Of course, the total effect on the immission would have to remain the same.

The criterion for such classification would be minimization of the total costs. The division of the traffic flow by types would be done in analogy with the licensing statistics. The total emission, then, might have the following appearance:

$$E_{CO_{\text{total}}} = a_1(\text{vehicles/hr})\cdot e_{CO_{\text{type I}}} + a_2(\text{vehicles/hr})\cdot e_{CO_{\text{type II}}}$$

$$+ \ldots\ldots + a_n(\text{vehicles/hr})\cdot e_{CO_{\text{Type } n}}$$

The factors $a_1, a_2, \ldots a_n$ indicate the relative proportions of the individual vehicle types, determined from the licensing statistics. These proportions are independent of the traffic volume in vehicles per hour. The sum of the factors is then equal to 1. For the division by types it is theoretically insufficient to limit the division only to the different manufacturers. Rather, it is necessary to consider all the different types of the individual manufacturers (e. g., according to horsepower and displacement classes). The same differentiation would be needed for the specific emission factors, $e_{CO_{\text{type } x}}$. Here we must consider that in order to obtain a representative value of e_{CO} for each type, a series of vehicles of this type must be measured. Finally, different ages should also be considered. The enormous measuring cost is apparent, even though such a program could in principle be carried out. The question would then be to formulate an optimization trial solution as follows:

Let the necessary reduction quota, R, be given for the total emission E_{CO} in % $(0 < R < 1)$. Then we have:

$$
\begin{aligned}
R\,E_{CO} = {} & a_1\,(\text{vehicles/hr})\cdot e_{CO_{\text{type } 1}}\cdot r_1 \\
& + a_2\,(\text{vehicles/hr})\cdot e_{CO_{\text{type } 2}}\cdot r_2 \quad + \;\ldots\; + \\
& a_n(\text{vehicles/hr})\cdot e_{CO_{\text{type } n}}\cdot r_n; \qquad i = 1, \;\ldots\; n.
\end{aligned}
$$

In this equation, we must determine the factors r_i, $i = 1, \ldots, n$, representing the percentage emission reduction for the particular vehicle types, under the condition that the total costs for these reduction measures shall be minimized, with $0 < r < 1$.

But now the costs for emission-reducing measures are functionally (unfortunately not linearly, apparently) dependent on the reduction quota:

$$k_{E_i} = f_i\cdot(r_i)\ , \quad i = 1, \ldots\ldots, n.$$

The minimization condition, accordingly, can be formulated as:

$$\sum_{i=1}^{n} f_i \; (r_i) = \text{Min!}$$

The important requirement that the e_{CO} must all refer to the same driving mode also applies for this trial solution.

This investigation could not take this economically desirable differentiation into consideration because of the lack of data. Rather, we considered homogeneous vehicle units, taking trucks into consideration.

Here we must discuss another differentiation which is in itself necessary. A large part of the measures to improve exhaust gases can technically be realized only with new vehicles. That would mean that the total goal of reducing all vehicles by some 40% can only be attained in part.

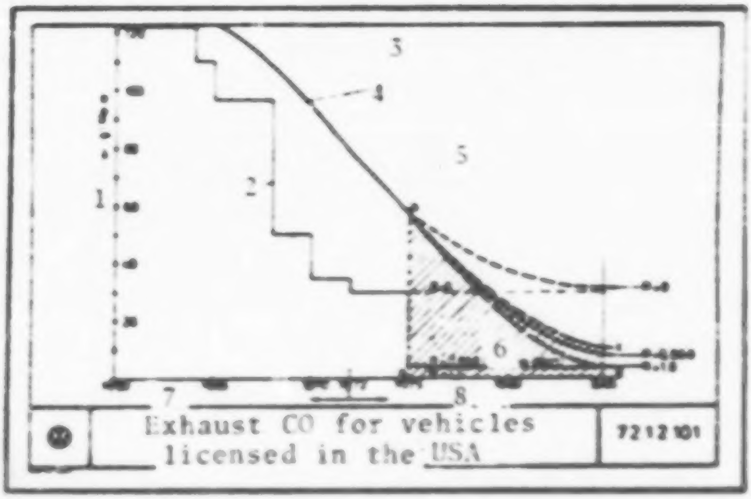
But on the other hand, it must be noted that the effect on the total emission, if only the newly appearing vehicles are equipped, will become notably effective only after a considerable time lag. The magnitude of this time lag will be determined by the growth of carpools and the average lifetime of the vehicles, which determines the regrouping quota. A diagram by Heitland makes clear the fact that even with very high reduction quotas for newly appearing vehicles,the total emission situation improves only gradually. This diagram represents the restructuring of the American vehicle population with time and the related effect on the total CO emission with alternative degrees of reduction (see Figure 8).

The figure shows clearly that nothing can be attained with respect to the total objective if the new vehicles are not subject to reduction quotas considerably greater than the average determined. The proportion of new vehicles in the total traffic population is simply too small for that. Reasonable legislation must include this technical-temporal restriction in its calculation.

In order to arrive at an idea of the total costs, under the assumption that only the new vehicles are equipped, we estimated the added costs for investment, maintenance and operation using a prediction for newly licensed vehicles up to 1982. The functions for the cost-reducing evaluation of the potential technical progress were taken into consideration. The costs were based on the values from manufacturer x, VW and the RECAT report. The result is presented in the following table (see Table 12).

While the total expenses for investment vary only slightly in direct dependence on new licensing, the maintenance and operating costs increase superproportionally due to the steadily rising portion of vehicles equipped with emission-reducing installations.

Equipping all of the newly licensed automobile population from 1973 to 1982 with exhaust gas-reducing measures would cause considerable expenditures, depending on the degree of pollutant reduction (see Table 12).



1 - CO pollutant emission

2 - Exhaust gas emission for the particular model year

3 - Carbon Monoxide CO

4 - Average exhaust gas emission of all licensed vehicles

5 - Area a, b, c, d = [illegible] = atmospheric pollutant load for the decade 75 - 85.

6 - Illegible

7 - Previous course

8 - Program

Figure 8. Source: Heitland, H. ..., cited elsewhere, p. 69.

Table 12. SUM OF THE INCREASED COSTS FOR EXHAUST GAS-REDUCING MEASURES FOR ALL NEWLY LICENSED CARS IN THE GERMAN FEDERAL REPUBLIC FROM 1973 TO 1982, DEPENDING ON THE DEGREE OF REDUCTION

- in millions of DM -

Model year	Emission reduction by			*			*			*			*			
	CO+HC 30 %, NO_x -			CO+HC 60 %, NO_x 30 %			all materials 93%			all materials 85%			all materials 90%			
	*	**	Σ	*	**	Σ	*	**	Σ	*	**	Σ	* (DM)	*⁺ (US$)	**⁺ (US$)	Σ (US$)⁺
1973 7-12	170,0	45,0	215,0	266,0	348,0	614,0	1290,0	709,5	1999,5	2236,0	2042,1	4278,1	1225,0	552,5	139,8	692,3
74	165,3	81,7	247,0	306,7	488,7	795,4	1229,0	1380,5	2609,5	2122,6	1968,9	4091,5	1041,5	718,4	271,6	990,0
75	115,0	163,0	278,0	303,7	966,3	1270,0	1136,3	2193,4	3329,7	1971,8	3733,9	5705,7	2040,7	603,6	432,4	1036,0
76	187,2	170,5	357,7	274,6	1138,8	1413,4	1103,3	2573,1	3676,4	1911,7	7209,5	9121,2	2716,7	641,0	509,3	1150,3
77	138,0	198,8	336,8	208,0	1121,0	1329,0	1079,2	3132,7	4211,9	1867,6	9021,1	10888,7	2576,2	626,9	617,5	1244,4
78	105,0	281,2	386,2	258,6	1778,8	2037,4	1019,0	3669,2	4688,2	1644,0	10748,3	12392,3	2445,0	610,7	719,8	1330,5
79	100,0	216,0	316,0	295,5	2031,5	2327,0	1053,6	4129,3	5182,9	1821,6	11994,0	13815,6	2474,6	614,9	858,1	1473,0
80	115,3	210,0	325,3	178,2	2144,2	2322,4	1042,1	4631,2	5673,3	1557,0	12275,6	13832,6	2403,3	607,2	911,5	1518,7
81	130,0	314,5	444,5	277,8	2433,2	2711,0	1140,0	4956,6	6096,6	1601,5	14367,7	15969,2	2199,7	606,4	983,6	1590,0
82	135,1	326,2	461,3	779,3	2183,2	2962,5	1106,3	5153,3	6259,6	1511,0	15255,8	16766,8	2113,5	609,6	1042,0	1651,6
Σ	1471,3	1569,8	3041,1	2896,1	13926,9	16781,0	11197,5	32409,8	43607,3	19185,6	93616,7	112802,3	21670,1	6450,7	6400,1	12850,8

The values for stages 30 - 85% are based on data from manufacturer A.

+ in US dollars

* manufacture

** maintenance and operation

IV. THE EFFECT OF REDUCTIONS IN PEAK TRAFFIC IN THE INNER CITY REGION ON THE ENVIRONMENTAL SITUATION

The route cost discussion within the European Community was terminated prematurely, to the extent that the commission recommended orientation to the concept of the social marginal costs with economic balance. This concept has not yet reached a stage of being ready for application, either for the suburban connecting routes or, much less, for the inner city region. In view of the pressing traffic problem of the cities, the Commission of the European Community has in mind avoiding an allocative-optimal solution as the first step in favor of direct marginal-cost-independent compensation systems. The targets of action are particularly the daily traffic peaks with their congestion phenomena. "The preceding considerations on differentiation in space also apply for differentiation in time. Here, too, the direct compensation should come into question only for traffic peaks which distinctly exceed the average traffic. Compensation for the traffic peaks is, of course, considered particularly necessary in the city areas . . . " (1). A congestion-dependent compensation system for inner city street traffic was also the objective of the Road Pricing Concept, oriented toward welfare economic criteria. Many kinds of objections, of both theoretical and operational nature, have since led the discussion on demand-controlling optimal pricing into a certain consolidation phase. Recently, an attempt has been made at the Institute for Traffic Science to develop a highly simplified but more practicable Road Pricing Model. "In place of an extremely differentiated loading mechanism with a filigree structure of optimal prices, there appears a pauschalized standard model of road pricing limited to some temporal, local and vehicle-related steps." (1). This trial solution consciously avoids any reference to the social marginal costs, and deals solely with an effective reduction of the degree of congestion. The height of the necessary price load for such an objective is determined by the price elasticity of demand.

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(1) Commission of the European Comunity (Editors), (Kom. (71) 268-end), Proposal for a Counsel decision on in[illegible]duction of a common system for compensation for utiliza[illegible]f traffic routes. Memorandum on compensation f[illegible] the [illegible]til-isation of traffic routes in the framework [illegible] traffic policy. Brussels, 24 March 1971, page 38.

This concentration on the traffic peaks results from the knowledge that the economically perceptible costs in the form of lost time, increased operating costs, increased accident rates and probably even greater environmental stress arise particularly from congestion phenomena. From the objective of reducing these costs, then, we can also determine the required reduction quota for the traffic peaks. The first ideas of such reduction quotas are about 30-40%. Hellmann determined this order of magnitude for establishing the objective of optimizing the operating costs as a function of the vehicle speed (2). The congestion is now decreased until the optimal speed for the operating costs is reached. Willeke and Baum propose similar quotas, but differentiated according to morning and afternoon peaks (30% and 40%, respectively).

Now the question of what contribution such a charging system can offer for improvement of the environmental situation is of interest here. In this respect, we must pursue the question of the form by which the environmental stresses from traffic are related to the degree of congestion. Here it is convenient to deal separately with noise and exhaust gases.

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(1) Willeke, R., Baum, H., Theory and practice of road pricing, in: Zeitschrift für Verkehrswissenschaft, Vol. 43, p. 69, 1972.

(2) Hellman, H., Congestion costs in inner city traffic. An economic study of the problem of individual traffic in congested centers, Karlsruhe, 1971, p. 148.

A. Noise

We must distinguish various effects for noise. For one thing, there is the physical relation that a doubling of the traffic volume increases the noise sensation by 3 dB(A). Therefore, as long as the traffic volume does not actually double with increasing congestion, this effect is < 3 dB(A). This increase is offset by a slight reduction in the level due to the decreasing speed. Furthermore, congestions lead to discontinuous traffic flow, and the starting, acceleration, and braking processes can lead to perceptible jumps in the level. If decongestion were linked with a significant gain in speed, this would also have a negative effect on the noise level (particularly for the rolling level). It is likewise clear that one significant aspect of traffic noise, disturbance of night rest by individual vehicles, does not correspond with congestion phenomena. Thus, a large part of the noise stresses would not be determinable with a charging system oriented toward the degree of congestion. Beesley has also referred to this relation: " . . . there may be an inverse correlation between the noise stress and the time of day at which the congestion fees will be the highest" (1).

The question of which tendency finally predominates, with the other effects, except for the night noise, differs from case to case.

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(1) Beesley, M. E., Technical possibilities for special taxation to counteract the blockages caused by street users (Second International Symposium on Theory and Practice in Traffic Economy, European Conference of Ministers of Commerce, editors), Paris, 6 April 1967, page 75.

B. Exhaust Gas Emissions

According to measurements by the Rhineland Technical Monitoring Union of a representative cross section of the German automobile population on a roller test stand, the following relations apply for the CO emissions:

- The CO emission in g/unit time decreases (almost proportionately) with decreasing average speed.
- The CO emission in g/unit distance rises superproportionately with decreasing speed.

The total effect can be interpreted as follows: Admittedly, the CO emission in g/unit time decreases with decreasing speed. But because the distance covered per time unit decreases with decreasing speed, a lower CO emission is applied over a shorter distance. The table clarifies the relation:

Table 13. CO EMISSION AS A FUNCTION OF THE DEGREE OF CONGESTION

Speed in km/hr	CO emission in g/km	Time/km	Time is held constant	Distance covered in 1.5 min	CO emission in 1.5 min., g
40	20	1,5 min.	1,5 min.	1,0 km	20
20	40	3 min.	1,5 min.	0,5 km	20
10	70	6 min.	1,5 min.	0,25 km	17,5
1	600	60 min.	1,5 min.	0,025 km	15

Therefore, if one characterizes congestion phenomena essentially through decreasing average speed, considering the speed-throughput relation, one can assume a positive correlation between the degree of congestion and the CO exhaust emissions. Without being able to quantify them, one could assume a similar tendency between congestion and immission. Thus it also seems possible to affect the exhaust gas situation in the inner city in a positive manner through a congestion-dependent charging system.

1. Effect on Exceeding the Short Term Value

The 14 excesses over the short-term limit of 30 ppm which are analyzed elsewhere in this work occurred solely during the usual traffic peaks, and especially during the afternoon peak between 15:30 and 18:30. The immission values are higher in the afternoon, not only because the traffic levels are also higher, but also because they develop upon a basic load which has increased during the day. The morning peak, by comparison, encounters a load near zero. This effect could correspond to a differentiated reduction quota of 30% for the morning and 40% for the afternoon.

The auxiliary proportionality hypothesis in the remaining analysis answers the question posed here immediately. The reductions in traffic volumes necessary to stay below the short-term limit are given. Of the 14 reduction quotas determined using the general functions, 11 are below 40%. For the values determined with the specific functions, the following relations appear: of 52 individual values, 32 are below 40%. If one forms the arithmetic average for each traffic volume, then 8 of 14 averages are distinctly below 40%, 3 values are just barely above 40% (41%, 40.6%, 45.6%), and only 3 would definitely not be reduced sufficiently by a 40% reduction in the afternoon peak. If one takes the average of all the individual quotas, both for the special and the general immission functions, then a congestion-oriented charging system for a 30 or 40% reduction in traffic peaks would ensure maintenance of the short-term limit of 30 ppm for CO. This value is 28.3% for the general functions and 31.1% for the specific ones.

2. Effect on Exceeding the Long Term Values

With the data available, it is difficult to judge what effect a 30 or 40% reduction in the traffic peaks would have on the long-term values, or what reduction in the peaks would be necessary to maintain the 24-hour average. Therefore, we tested the following trial solution: For 10 measuring days in which the long-term value was exceeded in metropolitan Cologne, three traffic peaks were studied, the times from 7:00 to 9:00, from 10:00 to 12:00, and from 16:00 to 18:00. There are 12 half-hour averages of the CO immission for these times. Now, in a simple additive trial solution, it is possible to calculate the percentage by which these 12 values must be reduced, with the other 36 half-hour averages remaining constant, in order to maintain a 24-hour average of 8 ppm.

For each of these twelve values of I_{CO}', we can determine the matching n' of the original function, according to the method described above, using the general immission functions. For each measuring day, then, one must obtain 12 reduction quotas for the traffic volumes, from which an average can be formed. But the great claim for general validity of the immission functions is still linked with a considerable range of variation, so that part of the empirical values cannot be analyzed. Then, for example, one obtains n' values (i. e., reduced traffic volumes) which are greater than the base amounts. Not a methodical, but a practical restriction arises from the fact that on some measuring days,the proportion of the traffic peak immission values in the sum of the immission values is so small that the prescribed limit of 8 ppm is obtained numerically through a 100% immission reduction of the peak values.

Because of these limitations, only three values gave a fairly reasonable basis for calculation (sites 3 and 9 for 30 December, and site 9 for 21 December 1971).

Table 14

Measuring site	Date	Immission reduction required	Calculated traffic volume reduction
3	4.11.71	73 %	72,3 %
4	8.11.71	80 %	51,9 % (1 value)
9	20.12.71	17 %	9,6 %
9	21.12.71	67 %	46,5 %
10	1.12.71	84 %	14,5 %(1 value)
10	2.12.71	78 %	34,1 %(4 values)

Except for measuring site 9 on 20 December 1971, all the necessary immission reductions for the other measuring days are so high that according to all the immission-emissions relations yet known, a reduction of the traffic volume by 30 or 40% for the three peak periods analyzed here would not be enough to reach the immission objective. The question of whether, in spite of that, considerable significance should not be attached to the decrease of the traffic volume maxima depends on the medical weighting of the absolute heights of the excesses of the half-hour averages over the limiting value, which are particularly great in traffic peak periods.

3. Financing Effect

Along with the positive effects on the immission situation, such a charging system also has a noteworthy financial effect. Depending on the elasticity of the demand, the remaining 60 or 70% of the traffic volume will pay a congestion tax per kilometer driven in the city.

We used the street traffic counts of the German city day, which were performed for the whole Federal area in 1965. For the individual classes of city sizes, we obtained the following yearly vehicle operations in vehicle kilometers (1 year = 250 working days):

Table 15

City size according to census	Annual driving of all vehicles in millions of vehicle kilometers
over 20,000	30,909
20 - 50,000	6,076
over 50,000	24,833
over 100,000	20,934
All the inner-city streets	85,260

As the congestion fees are directed only at the traffic peaks, the proportion of the traffic in these periods must be determined out of the total driving. Aside from minor fluctuations, one can assume that about 1/3 of the inner city total traffic can be assigned to the peak periods considered here (7:00 - 9:00, 10:00 - 12:00, 16:00 - 18:00) (see the count results of the Rhineland Technical Monitoring Union for metropolitan Cologne). Corresponding with this hypothesis, we get the following total driving during the peak periods:

Table 16

City size according to census	Annual driving in millions of vehicle kilometers
over 20,000	10,200
20,000 - 50,000	2,005
over 50,000	8,195
over 100,000	6,908
All the inner-city streets	28,136

After 30 or 40% reduction, the following amounts of driving remain; they are charged with a corresponding fee:

Table 17

Size of the city, according to the census	Reduction of peaks by 30%	Reduction of peaks by 40%
over 20,000	7,140 million vehicle-km	6,120 million vehicle-km
20,000-50,000	1,404 million vehicle-km	1,203 million vehicle-km
over 50,000	5,736 million vehicle-km	4,917 million vehicle-km
over 100,000	4,836 million vehicle-km	4,145 million vehicle-km
all the inner city streets	19,695 million vehicle-km	16,882 million vehicle-km

For the cities of the German Federal Republic, then, we can calculate the following fee incomes from such a charging system according to the city size class and assumed demand elasticity (see Table 18).

As such a system is conceivable as an alternative, but also in combination with increased emission-reducing measures, a comparison of the total monetary charges arising with one and the other would be of interest. But this comparison is hardly possible because the avoidance measures on the vehicle affect only part of the vehicle population, while a tax-like charging system to reduce the traffic peaks, in contrast, covers all vehicles. Inasmuch as technical restrictions actually make attainment of the immission goal through measures on the vehicle impossible because only part of the vehicles are equipped, a charging system appears more suited for a short-term attainment of the goal.

If one considers only the environmental goal, this fee system could be reduced in steps, depending on the rearrangement of the vehicle pool (continuously rising proportion of vehicles

Table 18. FINANCIAL EFFECT OF A PRICE-POLICY CHARGING SYSTEM FOR TRAFFIC PEAKS, DEPENDING ON THE PRICE ELASTICITY OF THE DEMAND, IN BILLIONS OF DM PER YEAR.

Elasticity	Price per km with 30% reduction, in DM	Price per km with 40% reduction, in DM	Cities of more than 20,000 population		20-50,000 population		over 50,000 population		over 100,000 population		all the inner city streets	
			at 30%	at 40%	30 %	40 %	30 %	40 %	30 %	40 %	30 %	40 %
0,2	0,30	0,40	2,1	2,5	0,4	0,5	1,7	2,0	1,5	1,7	5,9	6,8
0,4	0,15	0,20	1,1	1,2	0,2	0,2	0,9	1,0	0,7	0,8	3,0	3,4
0,6	0,10	0,14	0,7	0,9	0,1	0,2	0,6	0,7	0,5	0,6	2,0	2,4
0,8	0,08	0,10	0,6	0,6	0,1	0,1	0,5	0,5	0,4	0,4	1,6	1,7
1,0	0,06	0,08	0,4	0,5	0,1	0,1	0,3	0,4	0,3	0,3	1,2	1,4
1,5	0,04	0,06	0,3	0,4	0,1	0,1	0,2	0,3	0,2	0,2	0,8	1,0

equipped with exhaust-gas-reducing measures). Such a charging system also has advantages from the viewpoint of the causer incidence.

V. DAMAGES TO MATERIALS FROM AUTOMOBILE EXHAUST GASES (buildings, art objects)

Recent reports in the press and television suggest that significant damages to buildings are also occurring, and that these are of particular importance to the extent that they affect artistic monuments.

The Institute for Traffic Science has considered the problem with particular attention to the contribution from automobile exhaust gases. Along with intensive literature study, we also consulted scientists in this field. The answers were gratifying for traffic. All experts certified that automobile exhaust gases produce negligible damage to materials and artistic monuments. In this case, it is primarily sulfur dioxide which comes into question as the main cause "because in the presence of humidity it changes the calcite (calcium carbonate), which makes up the major part of limestone and marble and can be the binding agent for the quartz particles in sandstones, into gypsum:

$$CaCO_3 + SO_2 + \frac{1}{2} O_2 + 2 H_2O \rightarrow CaSO_4 \cdot 2 H_2O + CO_2 .$$

The gypsum crystallizes at the surface. It forms hard crusts at places in the shadow of the weather, where it is not dissolved by rain. The decomposition of the calcite continues under the crusts. The growing crust encloses dirt and soot particles, producing black surfaces which are very hard to clean". (1)

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(1) Riederer, Josef, Damage to Munich Art Monuments due to Air Pollution. Unpublished manuscript, 1972, p. 4 ff.

But only a small part of the SO_2 is emitted by street traffic (essentially by Diesel vehicles). For the Munich area, the total traffic portion of the SO_2 emissions was estimated as 4.9% (1). The other components of automobile exhaust gas, CO, CH, NO_x and Pb have no significant injurious effects on buildings. "The hydrocarbons from vehicles do not have a corrosive effect on rock, metal or glass. I do not know of any damages from nitrogen oxides, which might be expressed through nitrate formation. I have no experimental results on carbon dioxide, which, along with moisture, accelerates the dissolution of chalks. I know of no damages from lead." (2) Rieder of the Doerner Institute comes to the conclusion: "I would not estimate the damages from motor vehicles to objects of stone, metal and glass as high." (3).

Dr. Wolff, the master cathedral builder of Cologne, reported similar information. He attributed damages to the Cologne cathedral due to air pollution essentially to the reaction with sulfur dioxide and air moisture, described above (4).

Finally, we cite an American source. In the RECAT report, the damages to materials from gasoline-driven vehicles were estimated as $587 million for 1969 in the USA (5). But this figure should be considered with reservations because of the many methodical limitations.

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(1) Community policy aspects of environmental protection in Munich, Munich, 1971.
(2) Riederer, J., written information of 28 July 1972.
(3) Ibid.
(4) Oral information from master cathedral builder, Dr. Wolff.
(5) RECAT report, . . . , cited elsewhere, page 29.

As for the major component of the exhaust gas (CO), this was actually neglected by the RECAT committee: "This neglect of one of the major automotive pollutants is reasonable for all categories except 'health', since it is consistent with the known chemical inertness of CO to most materials and with the lack of definitive evidence that it has a deleterious effect on vegetation" (1).

Even though some effects of exhaust gases on materials might not yet be entirely explainable, it appears justified to exclude them from the analysis because the effects are considered very minor in comparison with the effects of other pollutants, especially of SO_2.

SUMMARY

1. As long as a direct assignment of damages and environmental stresses to street traffic is not possible, it is economically reasonable to evaluate only the expenses which are required to eliminate damages or to prevent them (preventive costs).
2. But it is a prerequisite for this indirect route that the relation between emission or its change and immission or its change can be produced. That is, a functional connection between emission and immission must be possible.
3. In this study, that difficulty was bridged over because, considering the proportionality hypothesis, the required emission reduction in % for the individual vehicle was determined through the required traffic volume reduction in %.

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(1) RECAT report, . . . , cited elsewhere, page 26.

Unfortunately, the necessary immission functions which describe the dependence of the immission on the traffic volume currently exist only for the pollutant CO.

4. Along with establishing similar immission functions for other pollutants also, it is likewise necessary to dimension the functions corresponding to the prescribed limiting values. In this work, for instance, we had available only functions of the half-hour averages for CO. They could be used for evaluation of the long-term excesses only by means of the average character of the long-term limiting value.

5. The specification of a short-term and a long-term immission limit also determined the two-part division of the work. In the first part, the excesses over the long-term limit recorded in metropolitan Cologne were analyzed. This was done both with the immission functions specified according to meteorological parameters, as well as with the general functions for which this differentiation was not undertaken. In both cases, average emission reduction quotas on the order of about 40% were determined for CO.
6. The analysis of the relatively few excesses over the short-term limit in metropolitan Cologne also led to similar results.
7. All the calculations cover data from measuring point 5 (0.75 m high, sidewalk edge); but the analyses using the generally valid functions could be extended to the other measuring points only with appropriately modified immission functions. Here again, the results in the form of the relative emission reductions did not diverge significantly.

8. After an "expense evaluation" in the form of the reduction quotas was successful in these first steps, these quotas next had to be transformed into absolute cost figures with the goal of determining the change of the costs as a function of the traffic volume. For this, we sought a scheme which would relate the required emission reduction as a function of the traffic volume, determined from the immission function and prescribed immission limit, to a "cost function" which describes the costs for exhaust gas-reducing measures on the vehicle as a function of the degree of reduction. In this system, boundary considerations in the sense of cost changes due to a few added vehicles are completely possible and reasonable.

9. Application of this scheme is limited to analysis of the short-term values. For the long-term values, it would first be necessary to define a function describing the dependence of the long-term immission value on the traffic volume. In principle, this would change nothing.

10. As before, data determination on the cost side encounters significant problems. Although many statements on exhaust gas reduction can be found in the international literature (see Table 8), systematic evaluation is difficult because the reports refer to different technical systems and the emission reductions to different periods. Only three German manufacturers participated in a questionnaire from the Rhineland Technical Monitoring Union as part of the current research plan, and only one of them had a large portion of the German automobile population. The statements from these manufacturers were used as "average" representative data for the calculations.

11. It is practical to separate the costs into one-time increased purchase costs on one hand and continuing higher maintenance, repair and operating costs on the other hand. The costs

were referred both to individual vehicles and to the total vehicle population of the Federal Republic.

12. For a general economic evaluation, optimizations in the form of the most cost-effective differentiation according to different vehicle types could be indicated only in general form. The same is true for the problem of the time lag for the total emission situation because of the slowness of the change in the vehicle composition. (The proportion of new vehicles with exhaust gas-reducing measures in the total population increases only gradually.)

13. In contrast, however, we attempted to estimate the effect of technical progress on the costs of such measures.

14. On the other hand, statements about "increased costs" are difficult to evaluate with respect to cost theory, partly because the market or sales-oriented portion is not known, nor is the differentiation of the costs for individual or mass production.

15. For the additional expenditures, it must be considered that they should not be attributed solely to CO reduction. Rather, a certain reduction stage with corresponding costs also has a positive effect on the emission of the other pollutants, CH and NO_x. In this work, for instance, which postulates a required CO reduction of some 40%, a measure is to be applied which also reduces CH by 40% and NO_x by 30% (reduction stage 2). Probably it would be technically and economically impossible, and certainly impractical, with the objective, to evaluate measures which serve only for CO reduction, because corresponding reduction quotas for the other pollutants cannot be determined in the lack of immission functions at present.

Therefore, the question of whether the different pollutants would give parallel quotas must remain undecided. If this were not the case, it must be taken into consideration that the reduction stage would be determined by the "worst" pollutant.

16. Beginning with the statements of the above-mentioned "most representative" manufacturer, assuming a lifetime of 9 years, we calculate the increased costs per vehicle for investment, maintenance, repair and operation at reduction stage 2 (40% CO and CH, 30% NO_x) as 1,600 DM. If we assume a certain technical progress, this amount can be reduced to 1,133.55 DM for a vehicle of the model year $t_o + 9$ ($t_o = 1973$), on the basis of prices in t_o.

17. In order to assign this amount to the actual causative action, the total costs were apportioned to the city kilometers driven (only here were the load limits exceeded). If we assume that a car is driven 5,000 km per year in the city (see the report of Dr. Glück), then for reduction stage 2 we get an amount of 3.56 Dpf per city kilometer driven, referred to the total lifetime. If technical progress is considered, this reduces to 2.53 Dpf. (The highest amount is calculated for reduction stage 80%, with 21.3 or 15.05 Dpf, respectively, per city kilometer).

18. Because the required measures can essentially be installed with acceptable cost only on new vehicles, we undertook an estimation of the costs for the total new licensings expected in the Federal Republic for the next decade (1973 - 1982). For the second reduction stage, we calculated a total amount of 18.8 billion DM. [If we assume that the entire car and station wagon population in the German Federal Republic on 1 January 1972 (15,475,600,

according to the Federal Automobile Office at Flensburg) could be equipped for stage 2, we get an amount of 4.95 billion DM. This value, to be sure, contains only maintenance, repair, and operational costs for 1 year.]

19. Along with the vehicle itself, we can also think of the traffic volume as an action parameter for improvement of the environmental situation. In the present study we investigated, with the background of European city traffic ideas, the immission improving effect which could be gained from a 30 or 40% reduction in traffic volume during the daily peak periods. One would attempt to attain this reduction through a tax-like, elasticity-dependent charging system. The following relations appear for the Cologne measurements:

    a) The excesses in the half-hour averages are essentially in the peak periods, and were eliminated, with very few exceptions, by a 30 to 40% reduction of the peaks.
    b) For the long-term values, on the other hand, only one reduction of the – maximal – 12 peak values (half-hour averages) on the order of magnitude mentioned above did not suffice to go below the long-term limit (8 ppm).

20. Besides the desired positive effect on the immission situation, such a charging system would also have a noteworthy financial effect. This attains the magnitude of billions, depending on the assumed elasticity and range of application (e. g., limitation to certain city size classes) (see Table 18).

21. Finally, it remains to be mentioned that automobile exhaust gases are much less responsible for damage to materials, especially buildings and art objects, than the SO_2 (sulfur dioxide) arising from other combustion processes. SO_2, in combination with water or air moisture converts the calcite in limestone, marble and sandstone to gypsum:

$$CaCO_3 + SO_2 + \tfrac{1}{2}O_2 + 2\,H_2O \rightarrow CaSO_4 \cdot 2H_2O + CO_2$$

In the opinion of the experts, the damages caused in this field by automobile emissions can be neglected.

APPENDIX

Table 8. SUMMARY OF LITERATURE STATEMENTS ABOUT THE INCREASED COSTS RELATED WITH EXHAUST GAS-REDUCING MEASURES.

a) Additional manufacturing costs (12)

Comment	Measures	Effect	Price increase per vehicle
1	No more detailed data	90% reduction of CO, HC, NO_x, referred to 1971.	$350
2	No more detailed data	" "	$500
3	Afterburner system, catalysts, exhaust gas recirculation, secondary air pump, change-over elements with control system	" "	over 1,000 DM + (1,200-1,800) M = 1,500
		70% reduction of all harmful materials	≈ 750 DM (= ½ of +)
		50% reduction of all harmful materials	≈ 375 DM (= ¼ of +)
4	Full catalytic exhaust aftertreatment	90% reduction of all harmful materials	540 DM
4	Thermal reactor, catalyst and exhaust gas recirculation	" "	1,260 DM
5	No more detailed data	maintenance of valid European limits	$15 - $65
6	No more detailed data	maintenance of the 1976 US limits except for NO_x	$240 above the 1971 model

Comment	Measures	Effect	Price increase per vehicle
7	No more detailed data	maintenance of the 1976 US limit except for NO_x	Results from questioning the American automobile industry $200-$500
8	European estimates for cars meeting the 1975/76 limits exported to the USA	90%	1975: $250-360 1976: $300-500
	Thermal afterburning	40% reduction of CO and HC, only minor reduction of NO_x (referred to 1972)	6-8% of an average vehicle
	Double catalysis	40% reduction of CO and HC, 70-80% reduction of NO_x, referred to the 1972 model	1% of an average vehicle
9	Exhaust gas recirculation	HC, CO unchanged; NO_x reduced by 30-50%, referred to 1972	1% of an average vehicle
	Improvement of Diesel engines (odor, smoke)	CO = 90% reduction; HC = 50% reduction; NO_x unchanged	5-10% of an average vehicle
	Gasoline engine, lean adjustment	CO = 80% reduction; HC = unchanged NO = 30-50%	3-13% of an average vehicle

There are no cost ideas for a series of new engines (electric motor, hybrid drive, steam engine, Stirling engine, gas turbine). Increased fuel consumption must be expected for all but the electric motor.

Comment	Measures	Effect	Price increase per vehicle
10	Combination of many measures listed individually on page 41 of reference 10.	meeting the American legislation	annual costs: 1966: $3 1968: $15 1970: $8 71/72: $14 1973: $60 1974: $20.60 1975: $193.40

Comment	Measure	Effect	Price increase
13 *	6 methods from a combination of exhaust gas recirculation, thermal reactor with and without air injection; ignition timing changed; change of mixture preparation, mixture preheating, valve control	Evaluated using the European driving cycle for a vehicle with 2,000 cm^3 displacement, 100 HP nominal power, 1,200 kg test weight and 12 liters basic consumption	The following increased costs were determined. They include 8% interest over 8 years.
		For 5 methods, a reduction of CO and HC to 70% of the 1971 value is attained	Increased purchase costs 34 - 540 DM; average ca. 70 DM. Total increased costs for 8 years 781-2,880 DM; average ca. 900 DM
		1 method leads to a reduction of 45% in CO, 40% in HC and 48% in NO_x	For this method, the maximum value above, applies: 540 or 2,880 DM
	2 methods from a combination of changed mixture preparation, oxidative catalyst with air injection, reduction catalyst, electrical cold start preheating, thermal reactor with air injection, exhaust gas recirculation	judged using the California test Method 102: 60% NO_x and HC reduction, 60% CO reduction referred to 1971	Increased purchase costs: 1,790 DM; Total increased costs for 8 years: 7,466 DM
		Method 107: 45% NO_x and HC reduction, 55% CO reduction referred to 1971	Alternative catalyst life 20,000 km: purchase: 1,100 DM total: 8,300 DM

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* Translator's note: Original foreign text does not have 11 or 12.

Comment	Measure	Effect	Price increase
			50,000 km: purchase: 1,100 DM total: 6,200 DM 80,000 km: purchase: 1,100 DM total: 5,800 DM
	Methods were also tested for truck and Diesel engines	not clearly stated	The purchase costs are between 566 and 751 DM. The total 8 year costs for 240,000 km driving are 6,270 - 7.410 DM

TABLE 3-3. – CONTROL TECHNIQUES AND ESTIMATED INVESTMENT COSTS FOR MOBILE SOURCE EMISSION CONTROLS 1967 – 1977 11)

Model Year		Autos and Light Duty Trucks Typical Changes or Controls Added	Additional Cost Per New Vehicle (Dollars)	Total Cost Per Vehicle (Cumulative) (Dollars)	Emissions Per Vehicle as Percent of 1967 Vehicle Level		
					HC	CO	NO_x
1967		None	0,00	0,00	100	100	100
1968-1969		Closed PVC system, carburetor changes, ignition timing changes, inlet air temperature control	5,40	5,40	53	45	111
1970		Additional carburetor changes, idle control solenoid, ignition timing changes	7,40	12,80	40	32	85
1971		Evaporative emission control, improved idle control solenoid with overheat protection (including transmission spark control), low compression ratios, additional carburetor changes	19,70*	32,50*	25	32	85
1972		Valve and valve seat changes for unleaded gasoline	2,00	34,50	20	28	69
1973-1974		Exhaust gas recirculation for NO_x control, speed controlled spark timing	48,00	82,50	20	28	42
1975	Alternative 1	Catalytic oxidation of HC and CO (includes long-life exhaust system), unitized ignition systems for 50,000 mile service-free performance, air injection for catalytic unit	163,50	246,00	12	16	42
1976-1977		Dual catalyst units for HC, CO, and NO_x; or tandem NO_x and CO-HC catalytic units; modified manifold reactors to reduce catalyst load	105,00*	351,00*	3	3	6
			Cumulative 1974	82,00			
1975	Alternative 2	Extremely lean fuel mixtures (unitized electronic ignition with electronic control of spark timing), electromechanical fuel injection, special valves and intake design	125,00	207,00	12	16	42
1976-1977		Low temperature NO_x decomposition catalyst unit	85,00*	292,00*	3	3	6
			Culmulative 1974	82,00			
1975	Alternative 3	Catalytic oxidation of exhaust HC and CO, air injection to assist catalytic unit	133,00	215,00	12	16	42
1976-1977		Exhaust gas recirculation increased to maximum for NO_x control. Modulation of recirculation	14,00*	229,00*	3	3	6

* abhove the cost of controls or simpler system replaced

APPENDIX H

Panel Estimate of Sticker Prices of Likely Emissions Hardware

Model Year	Configuration	Value[1] Added	Tooling[2] Amortization	Dealer[3] Margin	Profit[4]	List Price	Excise[5] Tax	Sticker Price
1956	PCV-Crank Case	1.90		.66	.29	2.85	.15	3.00
1968	Fuel Evaporation Control System	9.07	.50	3.30	1.43	14.30	.75	15.00
								(18.00)
1970	Ignition Timing	.61	.02	.22	.10	.95	.05	1.00
	Carburetor A/F Ratio	.61	.02	.22	.10	.95	.05	1.00
	Compression Ratio	1.24	.03	.44	.19	1.90	.10	2.00
	Transmission Control System	2.49	.05	.88	.38	3.80	.20	4.00
								(8.00)
1971 1972	Anti-Dieseling Solenoid	3.07	.10	1.10	.48	4.75	.25	5.00
	Thermostatic Air Valve	2.49	.05	.88	.38	3.80	.20	4.00
	Choke Heat Bypass	2.74	.05	.97	.42	4.18	.22	4.40
	Assembly Line Tests for California (1/10 Volume)	.18	.20	.13	.06	.57	.03	.60
								(14.00

Model Year	Configuration	Value[1] Added	Tooling[2] Amortization	Dealer[3] Margin	Profit[4]	List Price	Excise[5] Tax	Sticker Price
1973	EGR (11-14%)	5.48	.82	2.20	.95	9.45	.50	10.00
	Air Pump - Air Injection System	27.16	1.80	10.03	4.33	43.32	2.28	45.60
	Induction Hardened Valve Seats	.72	.55	.44	.19	1.90	.10	2.00
	Spark Advance Control	.48	.15	.22	.10	.95	.05	1.00
	Transmission Changes (Some Models)	.63	-	.22	.10	.95	.05	1.00
	Quality Audit Assembly Line for California (1/10 Volume)	.22	.02	.09	.04	.38	.02	.40
								(60.00)
1974	Precision Cams -- Bores - Pistons	2.44	.10	.88	.38	3.80	.20	4.00
	Induction Hardened Valve Seat V-8	.72	.55	.44	.19	1.90	.10	2.00
	Some Proportional EGR (10% @ 52.00)	3.21	.10	1.14	.49	4.94	.26	5.20
	Pretest Engines -- Emissions	1.80	.10	.66	.29	2.85	.15	3.00
	Catalytic Converter System for California (1/10 Volume)	4.02	.06	1.40	.61	6.09	.31	6.40
								(20.60)

Model Year	Configuration	Value[1] Added	Tooling[2] Amortization	Dealer[3] Margin	Profit[4]	List Price	Excise[5] Tax	Sticker Price
1975	Proportional EGR	29.71	-	10.30	4.45	44.46	2.34	46.80
	New Design Carburetor with Altitude Compensation	7.52	2.00	3.30	1.43	14.25	.75	15.00
	Advanced Air Injection Control	24.90	.50	8.80	3.80	38.00	2.00	40.00
	Air/fuel Preheater	2.87	.30	1.10	.48	4.75	.25	5.00
	Electric Choke (element)	2.67	.50	1.10	.48	4.75	.25	5.00
	Electronic Distributor (Pointless)	4.35	2.00	2.20	.95	9.50	.50	10.00
	Improved Timing Control ± 1°	1.40	.50	.65	.29	2.85	.15	3.00
	Catalytic (Oxidizing) Converter	18.86	4.00	7.92	3.42	34.20	1.80	36.00
	Pellet Charge 6 lbs @ $2.00 lb.	12.00	1.70	4.75	2.05	20.50	1.10	21.60
	Cooling System Changes	1.17	.10	.44	.19	1.90	.10	2.00
	Improved Underhood Materials	.63	-	.22	.10	.95	.05	1.00
	Body Revisions	.67	.60	.44	.19	1.90	.10	2.00

Model Year	Configuration	Value[1] Added	Tooling[2] Amortization	Dealer[3] Margin	Profit[4]	List Price	Excise[5] Tax	Sticker Price
1975	Assembly Line Changes	.08	.50	.22	.10	.90	.05	1.00
	End of Line Test Go - No Go	1.85	.05	.66	.29	2.85	.15	3.00
	Quality Emission Test	1.22	.05	.44	.19	1.90	.10	2.00
								(193.40)

Notes to Appendix

1. Either value added or hardware cost, including material, labor, overhead and general administrative costs.

2. Tooling and equipment amortized over three years.

3. As 22% of selling price.

4. As 10% of list price.

5. As 5% of sticker price.

TABLE 3-5. - ANNUALIZED UNIT COST INCREASES FOR LIGHT DUTY VEHICLES
(Dollars)

Cost Type / Model Year	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977
Increased Fuel Use				15.90	15.90	21.50	21.50	40.60	40.6[illegible]	4[illegible].60
Maintenance	6.10	6.10	6.10	12.70	12.70	15.50	15.50	50.10[1]	60.4[illegible][1]	[illegible].40[1]
Maintenance Offsets								-36.30[2]	-36.30[2]	-[illegible].30[2]
Total Annual Operating and Maintenance	6.10	6.10	6.10	28.60	28.60	37.00	37.00	54.40	64.[illegible]0	[illegible].70

[1] Based on average of Alternative 1 for 1975-77 shown in Table 3-5.

[2] Offsets for reduced requirements for present type tune-ups and exhaust system maintenance.

Comments on a) Additional Manufacturing Costs

1) Final Report of the Ad Hoc Committee on the Cumulative Regulatory Effects on the Cost of Automotive Transportation (RECAT). Prepared for the Office of Science and Technology, no location, 28 February 1972, p. ix.

2) Average of estimates from the American automobile industry. Source: RECAT report, p. ix.

3) Heitland, H.: Problems of exhaust gas detoxication (cost-utility consideration) in: Traffic Safety - Slogan or Meaning? [= Literature Series of the Automobile Industry Association (VDA)], Frankfurt am Main, 1972, p. 66 ff.

4) Welbergen, I. C., Auto and Environment – where is the trip going? in Oel, Nov. 1971, p. 311.

5) Extract from an OECD working draft: "The Economics of Clean Air", Chapter V: "The costs and effects of reducing vehicle noise and air pollution", no location or date, p. 5-3 ff.

6) Semiannual Report Prepared by The Committee on Motor Vehicle Emissions, Division of Engineering, National Research Council, in accordance with Section 202(c) of the Clean Air Amendments of 1970 and in partial fulfillment of Contract No. 68-01-0402 between the Environmental Protection Agency and the National Academy of Sciences (Publ.), Washington, Jan. 1972, page 43.

7) Ibid, p. 40.

8) OECD working draft, cited elsewhere, p. 5-10.

9) Automobile and Environmental Damage – For an Action Program, translation of a report by a group of French automobile experts under contract to the License Ministry, no location, 1972, p. 72 ff.

10) Semiannual Report, cited elsewhere, p. 41, 43. The Commission attempts to classify the consumer price into:
   a) Value added (either value added or hardware cost, including material, labor, overhead and general administrative costs.
   b) Amortization of tools and equipment over 3 years.
   c) A trade margin of 22% of the selling price.
   d) A profit of 10% of the list price.
   e) 5% of the final selling price as sales tax (see the tables on pp. 106-109).

11) The Economics of Clean Air, Annual Report of the Administrator of the Environmental Protection Agency to the Congress of the United States, Washington, 1972, p. 3-9.

12) The other costs and prices reported in the literature do not yet take the 1975/76 American limits into consideration, and were therefore not explicitly included in the listing. See: Ford, I. W., Elgass, G. A., Weihmiller, H. E., "The automobile and the economy", in: The Automobile and Air Pollution, U. S. Department of Commerce (Publ.), Part II, Washington, Dec. 1967, p. 89 ff; U. S. Department of Health, Education and Welfare, Public Health Service - Environmental Health Service, NAPCA (Publ.): "Control techniques for carbon monoxide,nitrogen-oxide and hydrocarbon emissions from mobile sources", Washington, 1970, p 4-8 ff; First Report of the Secretary of Health, Education

and Welfare to the Congress of the United States (Publ.): The Cost of Clean Air, Washington, 1969, p. 84 ff.

13) Dornier System, Emission reduction in traffic; Effectiveness and costs of measures to reduce pollutant emission from vehicles, Summary of the final report of July 1972, September 1972, p. 11 ff.

b) Additional maintenance, repair, and operating costs per vehicle and year

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1. The RECAT report estimates $65 per car per year. In the course of technical progress, this would decrease to $45 per year after 10 years, with constant prices. (1)

2. The Annual Report estimates $64.70 per vehicle per year for 1977 (2).

3. The Environmental Protection Agency (EPA) reports
   $72 per vehicle per year for 1975 (3)
   $93 per vehicle per year for 1976.

4. Welbergen, cited elsewhere, p. 312, reports the following values:

Measure	Operation with Leaded Fuel	Operation with Unleaded Fuel
Two-bed catalyst	424.50 DM/yr	200.50 - 215.50 DM/yr
Thermal reactor + exhaust gas recirculation + oxidative catalyst	729.50 DM/yr	505.50 - 520.50 DM/yr

5. Estimated increases in gasoline consumption because of absence of lead and exhaust gas recirculation.

(4)	3 - 12%
(5)	≤ 30%
(6)	6% after model year 1971; another 2% after 1973, and another 7% after the 1975 model year.
(7)	≤ 30%
(8)	9 - 34%
(9)	5 - 35%
(10)	10% for 1975/76 with a gradually falling tendency

Notes:

1) RECAT report, cited elsewhere, p. xx
2) Annual Report, p. 3 - 22.
3) OECD working draft, cited elsewhere, p. 5-11
4) Semiannual Report, cited elsewhere, pp 42, 49
5) Fersen, Olaf v., Automobile Exhaust Gas Detoxication, in: International Traffic, Vol. 23, p. 151, 1971.
6) Annual Report, cited elsewhere, p. 3-21
7) Heitland, H., cited elsewhere, p. 5
8) Welbergen, I. C., cited elsewhere, p. 312
9) Johnson, I. E., Appendix I-C of the RECAT report, cited elsewhere, p. I-C 1.
10) RECAT report, cited elsewhere, p. 22
11) The increased fuel costs due to lead-free gasoline must be compared with reduced maintenance costs for spark plugs and mufflers, at the level of 20 DM/year. See Welbergen, I. C., cited elsewhere, p. 311.

c) (1) Additional investment costs required in the petroleum industry for lead reduction, as a function of the degree of reduction:

0.11 cm^3/l	0.06 cm^3/l	Lead content = 0
Capital investments (1) $3.7 million for a refinery with a daily capacity of 30,000 barrels/day	$3.9 million (1) for a refinery with a daily capacity of 30,000 barrels/day	$13.2 million (1) for a daily capacity of 30,000 barrels/day
$13.1 million for (1) a daily capacity of 240,000 barrels/day	$18.4 million (1) for a capacity of 240,000 barrels/day	$55.8 million (1) for a daily capacity of 240,000 barrels/day
		Lead content 0.15 g/l (2)
		1.3-1.5 billion DM for the entire petroleum industry of the German Federal Republic
		1-1.5 billion DM (3) for the entire petroleum industry.

1) Air/Water Pollution Report of 17 May 1971, p. 205. Here reference is made to a study by the Foster Wheeler Corp., Livingston, N. J., (no year cited).

2) Fersen, Olaf. v., cited elsewhere, p. 151.

3) Lectures by Prof. Heitland (VW) in Cologne and Hamburg.

(2) The increased costs will have the following effects on the price of gasoline:

0.11 cm^3/l	0.06 cm^3/l	Lead Content = 0
0.02 - 0.2 Pfg/l	0.1 - 0.3 Pfg/l	1.42 Pfg/l (1)
		0.77 Pfg/l - 2.5 Pfg/l (2) Average ≈ 1.4 Pfg/l
		2 - 3 Pfg/l (3)
		1.8 Pfg/l (4)
		1.3 - 3.3 Pfg/l (5)

(1) Air/Water Pollution Report, cited elsewhere, p. 205

(2) Annual Report, cited elsewhere, p. 3-19 ff.

(3) Welbergen, I. C., cited elsewhere, p. 312.

(4) Control Techniques, . . . , cited elsewhere, p. 6-5.

(5) Johnson, J. E.: Appendix I-C to RECAT report, p. I-C 4.

(+) Dollar amounts were recalculated at the rate of $1 = 3.20 DM.

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